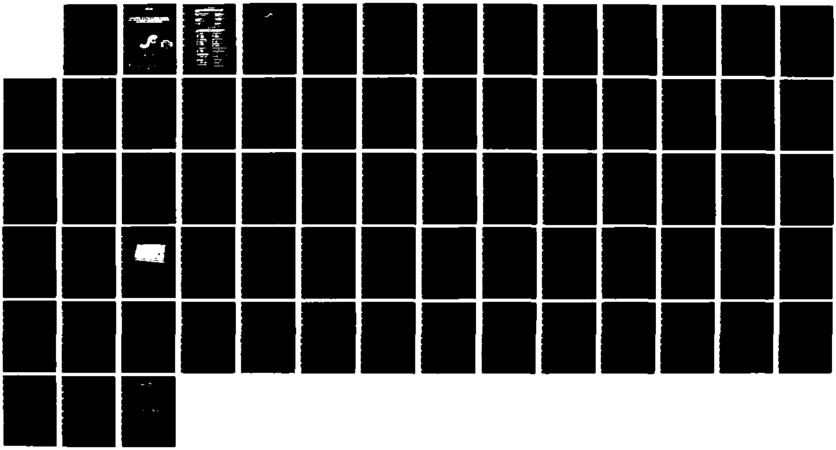
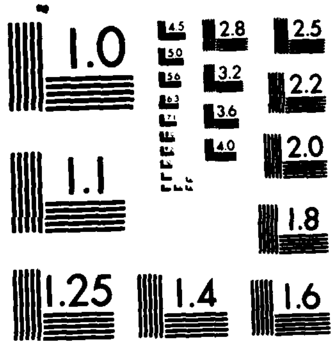
AD-A162 560 DEVELOPMENT OF A PLAN TO OBTAIN IN-SERVICE STILL WATER BENDING MOMENT INF (U) GIANNOTTI AND ASSOCIATES INC ANNAPOLIS MD J W BOYLSTON ET AL OCT 82 GA-11-119 1/1

UNCLASSIFIED SSC-319 DTCG23-82-C-20002 F/G 13/10 NL





MICROCOPY RESOLUTION TEST CHART
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Ship Structure Committee

An Interagency Advisory Committee
Dedicated to the Improvement of Marine Structures SR-1282

Address Correspondence to:

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Although there have been many instrumentation programs directed at measuring full-scale midship bending moment variations due to wave loadings, there has been no comprehensive attempt to directly ascertain the still water bending moments (SWBM) which are necessary to determine the total bending load experienced.

This report reviews previous instrumentation programs and recommends programs to gather SWBM data in sufficient quantity to be useful for statistical characterization and for obtaining SWBM envelope curves. Included are cost estimates, desirable equipment and its calibration, data recording, data processing, data reduction and data analysis considerations. Keywords: Ship Structures.

It is expected that the Ship Structure Committee will begin gathering SWBM data on their other instrumentation projects so as to make the program most cost effective.

CLYDE T. LUSK, Jr.
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

Technical Report Documentation Page

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16. Abstract

The pursuit of a probabalistic based hull girder load criteria for ship structural design has lead to the development of a test plan to obtain still water bending moment (SWBM) data for in-port and at-sea conditions. Several approaches for obtaining SWBM data are considered including estimation of SWBM from manual calculations, from loading computers, and from instrumentation which would be used to measure SWBM induced strain. Recommendations are presented to obtain the SWBM data from a combination of techniques including loading computers and an instrumentation system. A preliminary plan describes the data acquisition system, data reduction and data analysis required to obtain and characterize the SWBM data in a probabalistic format.

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UNCLASSIFIED	UNCLASSIFIED	59	

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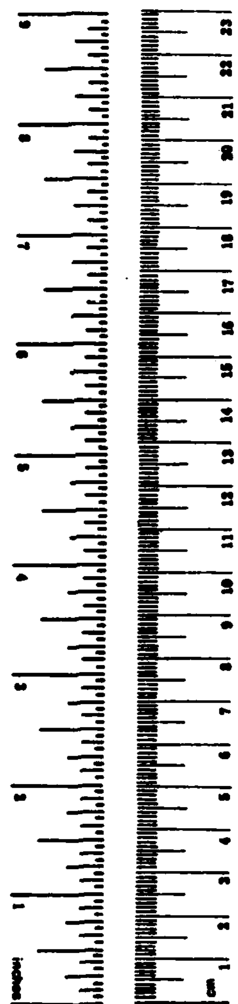
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

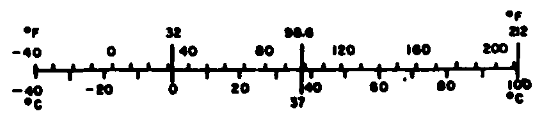
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

The development of a ship structural design procedure which is based on probabilistic methods includes the analysis of ship structural response data induced by various load sources. These loading sources include wave-induced, dynamic impact (slamming, whipping), still water bending and thermal effects. *Extensive research and data analysis have been conducted to* determine the probabilistic nature of wave-induced and dynamic impact loading and response. Several studies (1, 2, 3)* have indicated that there is minimal data available to determine the probabilistic nature of still water bending moment (SWBM) loading on ship structures. A research program has been initiated by the Ship Structure Committee to obtain full-scale SWBM data to support the development of a probabilistic design method.

The ship structural loading, traditionally called SWBM, has been defined as the sum total of weight and buoyancy of the ship hull in calm or still water. The weight component of the SWBM is composed of the weights of the hull structure, machinery, fuel, ballast, cargo, crew and consumables for most ships. Variations in SWBM as traditionally defined are caused primarily by cargo, ballast and fuel distribution. Full-scale at-sea instrumentation programs conducted in the late 1960's indicated that large variations in hull loading are also caused by variations in ballast and fuel distributions in normal at-sea operations. While the cause of this at-sea variation is the same as in still water (except that there are normally no variations in cargo), the loading is no longer occurring in still water. Wave-induced bending moments, ship's own wave train bending moment and thermal effects typically occur simultaneously. The actual SWBM, therefore, becomes much more elusive in definition and characterization for the at-sea conditions.

The objective of this study is to develop a plan to obtain in-service still water bending moment data. The program should obtain data to facilitate the calculation of SWBM from deadweight loading information and instrumentation. Data would be acquired while in port during ship loadings and at sea when variations in cargo, ballast and fuel will change SWBM. The data would be obtained to eventually characterize the SWBM from a probabalistic design standpoint. This would include determining how the SWBM data varies statistically or deterministically throughout a ship's life.

2.0 BACKGROUND AND OVERVIEW OF PAST STUDIES INVOLVING STILL WATER BENDING MOMENT

One fundamental input to the desired rational ship structural design method is the load envelope of which the SWBM is a critical component. Several studies have proposed methods to characterize SWBM statistically and have encountered numerous problems associated with the existing SWBM data both calculated and measured. This section presents a summary of these studies and limitations of past SWBM data discovered by the researchers.

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* The numbers in parentheses indicate references listed at the end of the report.

2.1 STATISTICAL APPROACH TO CHARACTERIZATION OF SWBM

The work presented in report SSC-240 (1), Load Criteria for Ship Structures Design, was an attempt to develop the ultimate load criteria for the main hull girder involving the following bending moments:

(a) Still water due to weight and buoyancy
(b) Ship's own wave train
(c) Quasi-static wave-induced, vertical and lateral combined
(d) Dynamic, including slamming, whipping and springing
(e) Thermal effects

Determination of each of the loads was reviewed and the methods of combining loads, all expressed in probability terms (including the SWBM) were considered in SSC-240. Based on computations using actual cargo conditions and data from the loading manuals, histograms of SWBM were developed for the containership NEW ORLEANS, the tanker ESSO MALAYSIA and the ore carrier FOTINI L. These are shown in Figures 2-1, 2-2 and 2-3. The authors (1) have tentatively concluded that for containerships a single distribution curve for still water bending moments may be established during design for a particular service. In the case of tankers and bulk carriers, two distribution curves are usually required, one for loaded and one for ballast conditions.

In 1975, Ivanoc and Madjoarov (4) calculated the SWBM from cargo plans of eight ships over seven years of operation for fully and partially loaded conditions. The results of their calculations for the ratio of SWBM to $SWBM_0$ are shown in Figure 2-4.

Dalzell reported in SSC-287 (2) on efforts to determine the character of SWBM. Unfortunately, the data used in this project was not considered adequate for the determination of the SWBM based on actual operating experience of the three ships considered.

In summary, there is a good base of analytical data on the statistical character of SWBM, but the data is not of sufficient quantity for statistical analysis.

2.2 PROBLEMS ENCOUNTERED IN DETERMINING SWBM BY PREVIOUS INSTRUMENTATION PROGRAMS AND STUDIES

There are numerous full-scale instrumentation programs which have been conducted to obtain operational stresses. Several ships have been instrumented with hull response packages for various government and private sectors. These ships include the HOOSIER STATE, WOLVERINE STATE, MORMACSAN, CALIFORNIA BEAR, BOSTON, UNIVERSE IRELAND, NEW ORLEANS and SL-7 SEA-LAND McLEAN. In many cases, measurement of midship bending stress has been the primary data target; and in some cases, measurements have been made at other locations of special interest.

The difficulties in obtaining a probabilistic distribution of still water bending stress from existing data have been documented in SSC-240 (1),

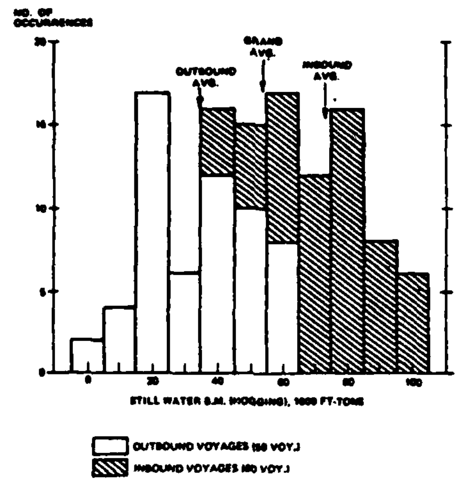


Figure 2-1 Histogram of Still Water Bending Moments, Containership *NEW ORLEANS*

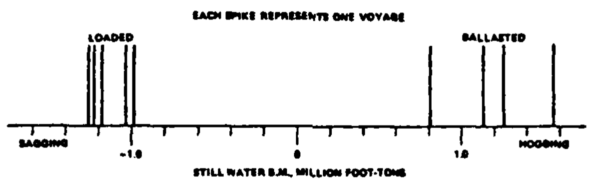


Figure 2-2 Typical Still Water Bending Moments, Tanker *ESSO MALAYSIA*

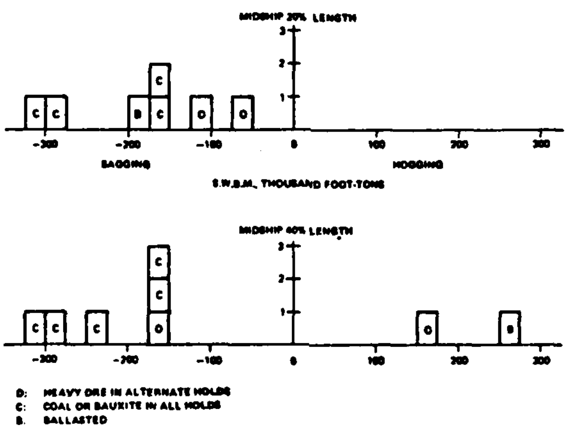


Figure 2-3 Typical Still Water Bending Moments, Ore Carrier *FOTINI L.* Each box represents one voyage

(from Reference 1)

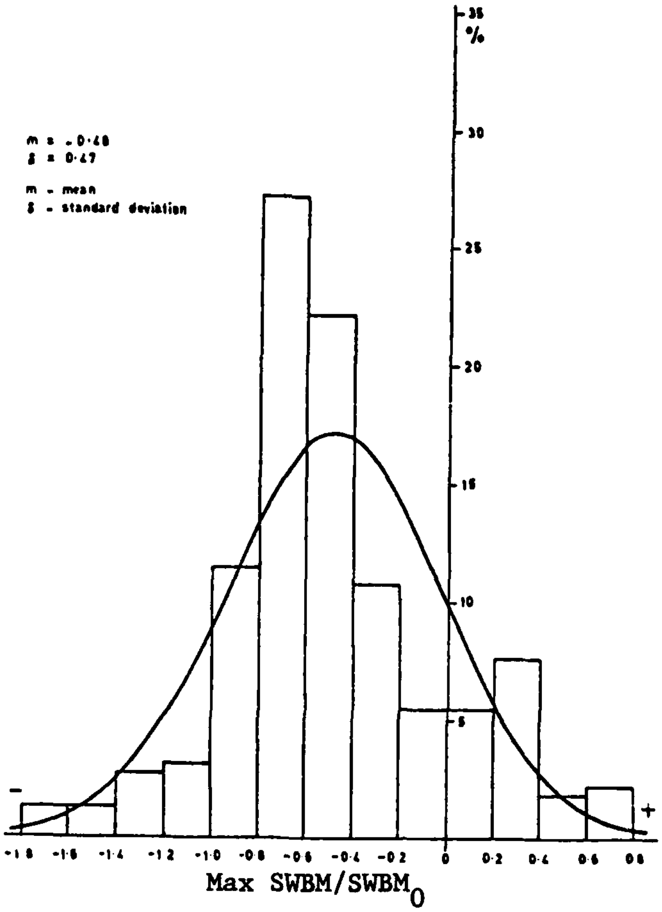


Figure 2-4 Frequency Distribution and Histogram of Max $SWBM/SWBM_0$ for a General Cargo Ship and Two Bulk Carriers

(from Reference 4)

SSC-287 (2), and reference 3. These problems include limited amounts of data associated with loading conditions, incomplete measurement of full-scale stresses and data processing techniques.

A pilot study was described in SSC-240 (1) to obtain enough actual still water bending moments for the containership NEW ORLEANS, the supertanker ESSO MALAYSIA and the bulk ore carrier FOTINI L in the outbound and inbound loading conditions to evaluate their statistical distributions, including mean values and standard deviations for outbound and inbound voyages. The study indicated that in many cases, especially for tankers and ore carriers, loading data are not sufficiently detailed to permit accurate assessment of bending moments. The total amount of ballast is usually recorded, but its actual distribution is left to the judgement of the ship's officers who were not required to record the quantities allocated to each ballast tank; nor were records of ballast shifts at sea during tank cleaning operations retained. Therefore, significant variations in still water bending moment may actually occur but cannot be calculated from recorded voyage data.

The still water bending moments were investigated as part of the load criteria development study presented in SSC-287 (2). The objectives of the study were similar to those presented in SSC-240 with additional investigations into the probabilistic nature of the still water bending stresses on the containership SL-7 SEA-LAND McLEAN, the tanker UNIVERSE IRELAND and the bulk carrier FOTINI L.

The authors (2) concluded that they did not have the data required to calculate the still water bending moment based on actual operating experience for any of the three ships. The cited difficulties were again related to inadequate description of loading distribution of cargo, ballast and consumables for each of the study ships. The authors (2) also found that where data on loading did exist it was costly to retrieve. This situation precluded the reconstruction of actual experimental load conditions and the calculation of the corresponding still water bending moments. The study (2) discussed several qualitative observations obtained from the reconstruction of still water bending stress time histories. The reconstructed plots of still water bending stress for selected voyages are shown in Figures 2-5, 2-6 and 2-7 for the SL-7 SEA-LAND McLEAN, FOTINI L and UNIVERSE IRELAND, respectively. It was pointed out in SSC-287 (2) that the variations result from a number of sources which include changes in ballast, consumables, thermal effects and ship's own wave train. The techniques required to separate the types of stresses are extremely difficult and in many cases complete separation may be impossible. SSC-240 (1) and SSC-287 (2) present methods for separation of thermal stresses where they dominate, but the methods are admittedly approximate at best.

An additional and very significant feature depicted in Figures 2-5, 2-6 and 2-7, and discussed in SSC-287 (2) is the zero stress at the start of each voyage. The data recording procedure employed for the majority of full-scale instrumentation programs was to zero the instrumentation at the beginning of each voyage to avoid signal saturation. The plots then depicted the values of mean stress relative to the zero at the start of each voyage. Thus the initial mean still water bending stress that results from the placement of

Ship: SEA-LAND McLEAN
Trip: 25E Route North Atlantic
Date: 9/23/73 - 9/26/73
TMR Tapes: 101 & 103

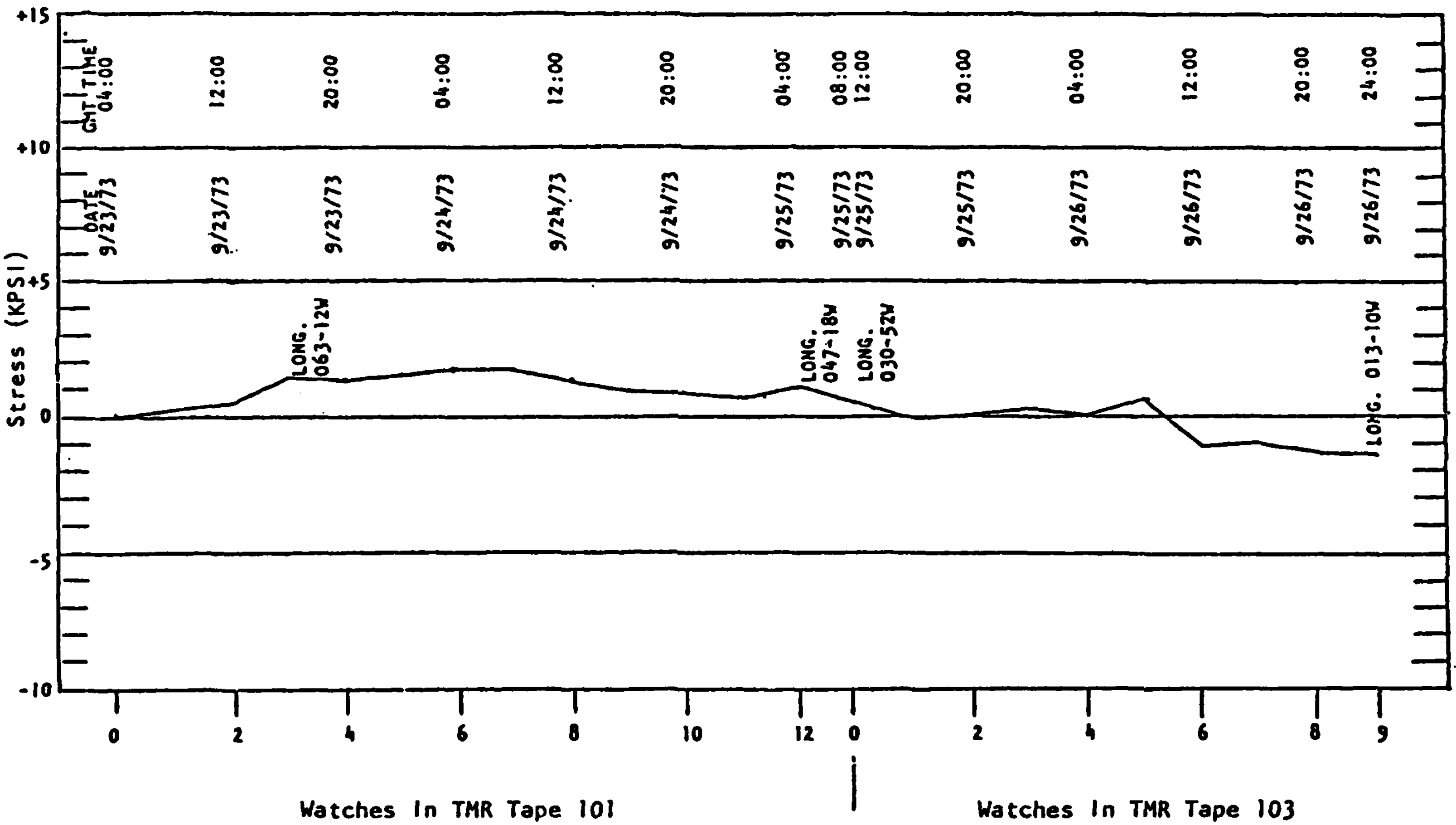


Figure 2-5 SL-7 - Typical Voyage Variation Of The Relative Still Water Stresses

(from Reference 2)

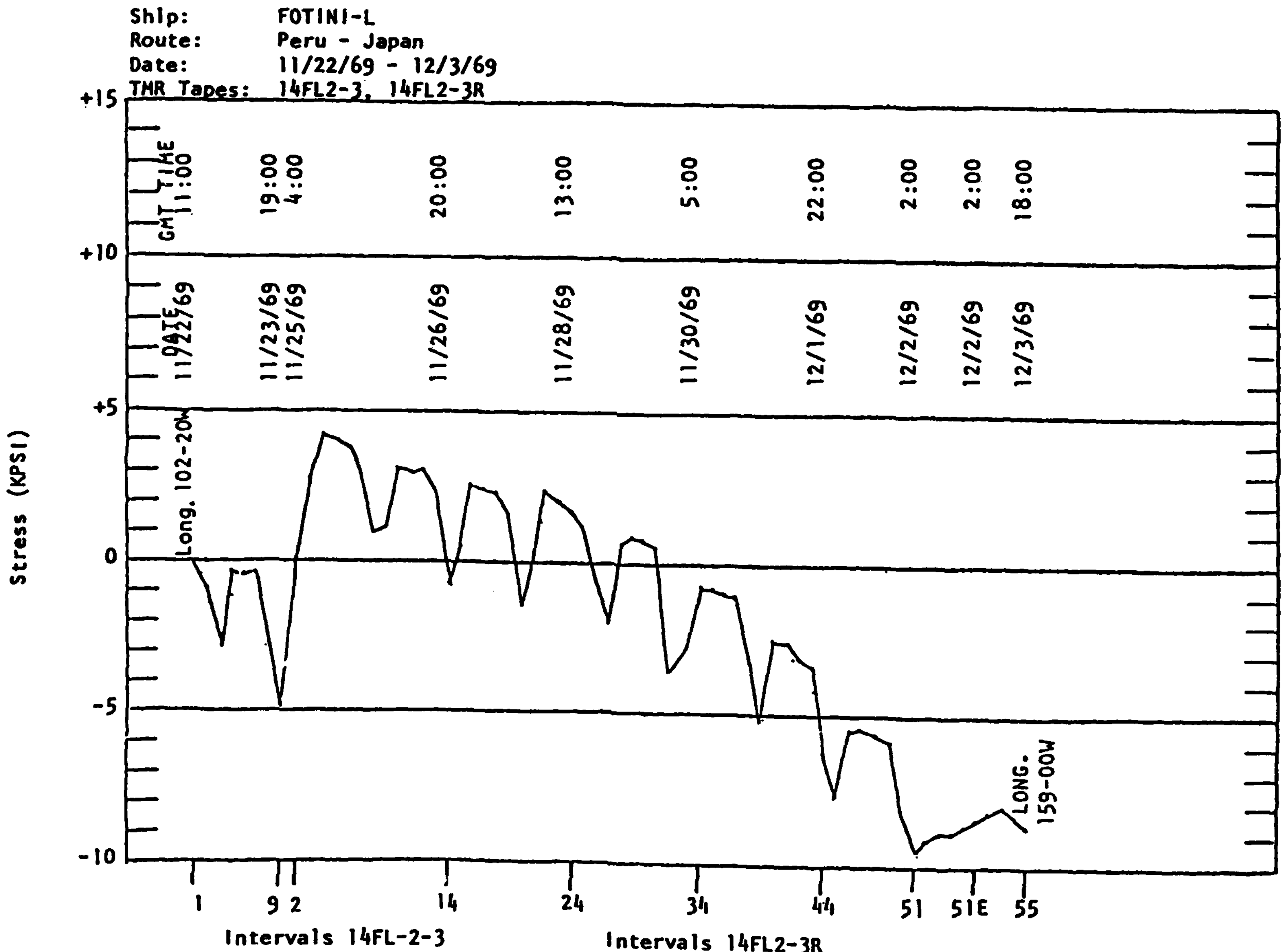


Figure 2-6 FOTINI L - Typical Voyage Variation Of The Relative Still Water Stresses

(from Reference 2)

Ship: UNIVERSE IRELAND
Route: Persian Gulf - Western Europe
Date: 12/24/69 - 1/23/70
TMR Tape No: 7U12-7R, 7U13-7, 7U13-7R

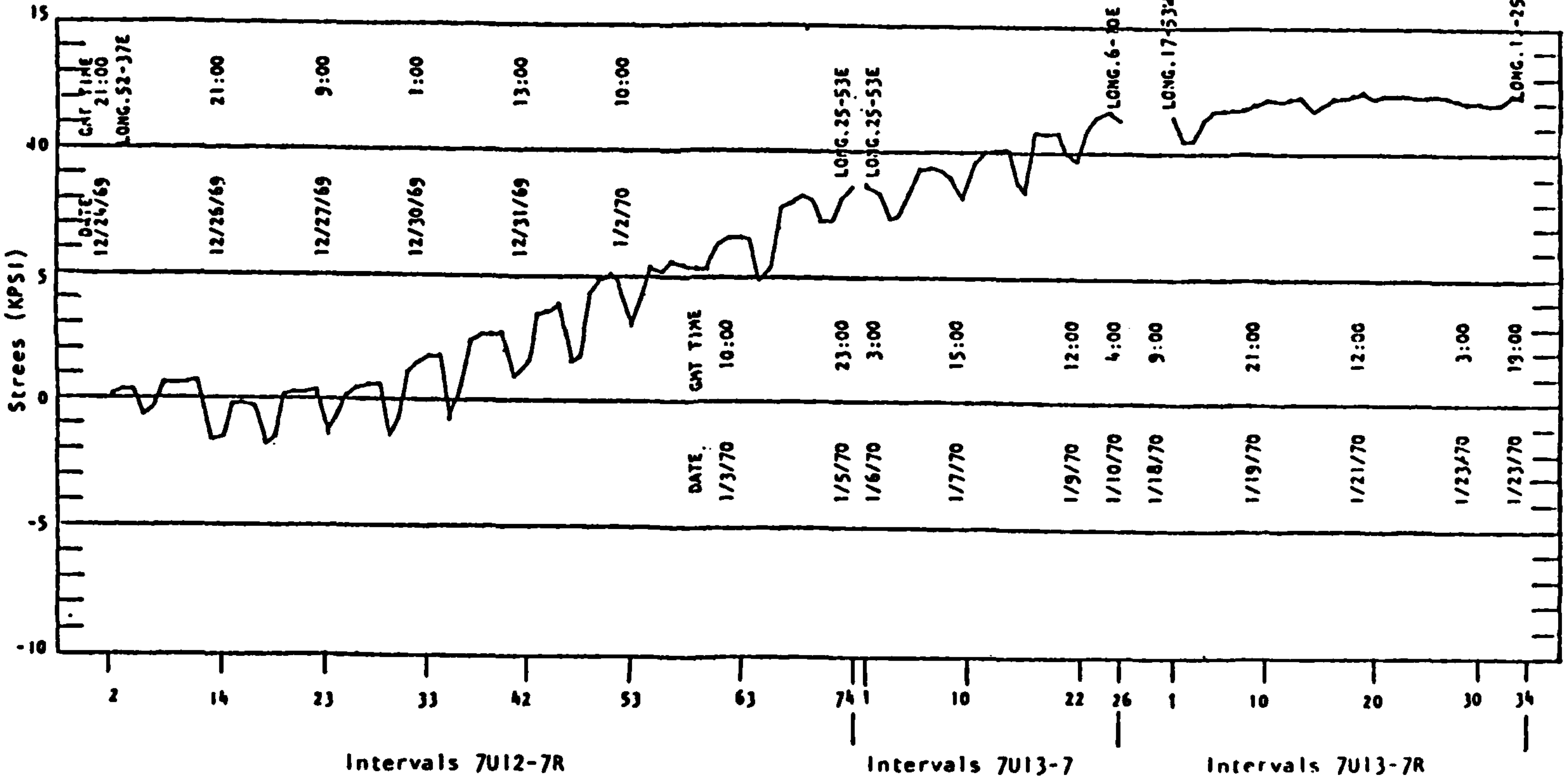


Figure 2-7 UNIVERSE IRELAND - Typical Voyage Variation Of The Relative Still Water Stresses

(from Reference 2)

cargo is not included in the recorded data and has not been recorded in any manner before the gauges were zeroed. This represents the major shortcoming of existing data for determining the nature of still water bending stresses.

Another difficulty in reconstructing a complete picture of still water bending stress is related to the data acquisition techniques employed to acquire ship response data (including stress) for the majority of the full-scale instrumentation programs that have been conducted for SSC in the past. For practical consideration, full-scale data has traditionally been collected in sampling patterns. These patterns consist of recording data for 30-minute intervals typically two out of every four hours. This pattern is depicted for SWBM in Figure 2-8 for the SL-7 SEA-LAND McLEAN data (9) instrumentation program. This technique is employed because of data acquisition hardware limitations. It would not be practical to record the stresses on a continuous basis for a single voyage, let alone several voyages, thus some data acquisition scheme has to be employed. The procedure used in reducing data to obtain still water bending stress includes filtering out all high-frequency wave-induced stresses that may result from whipping, slamming, springing, etc., and then calculating the mean stress from the average of the wave induced cycles for each 30-minute recording interval. As previously indicated, this mean stress is referenced for each interval to the initial zero stress at the beginning of each voyage. Thus, the mean stresses depicted in Figures 2-5, 2-6 and 2-7 are reconstructed from the average interval information. In short, there is no such thing as a stress time history for at-sea SWBM-induced stress. The data acquisition procedure obtains the mean stress by calculation procedures. This situation is further complicated by the addition of thermal effects and bending stress induced from the ship's own wave train.

3.0 VARIATIONS OF SWBM AND DISCUSSION OF SOME SHIP TYPES FOR THE STUDY

The variations of SWBM in port and at sea have been considered in the selection of ship types that would be of interest for further investigation of SWBM. Other considerations related to ship availability also played a role in the selection of candidate ship types. These considerations included the operational procedures, future modification of tankers to segregated ballast capabilities, and owner interest. In this section recommendations are presented for the ship types of interest for characterization of SWBM loading data.

3.1 MEASURED VARIATION OF SWBM DURING DOCKSIDE LOADING AND AT SEA CONDITIONS

Several research projects have reported on the variations of SWBM. The studies of interest here include the American Bureau of Shipping (ABS) tanker instrumentation program (sponsored by ABS) (5) and the SL-7 instrumentation program (6) (sponsored by SSC, ABS and Sea-Land).

The variation in bending stress induced by variations in SWBM that resulted from the loading of cargo for the UNIVERSE IRELAND (tanker) and the FOTINI L (bulk carrier) are presented in Figures 3-1 and 3-2, respectively. These plots depict variations in longitudinal vertical bending stress as a function of time for various locations along the ships. The general trends of

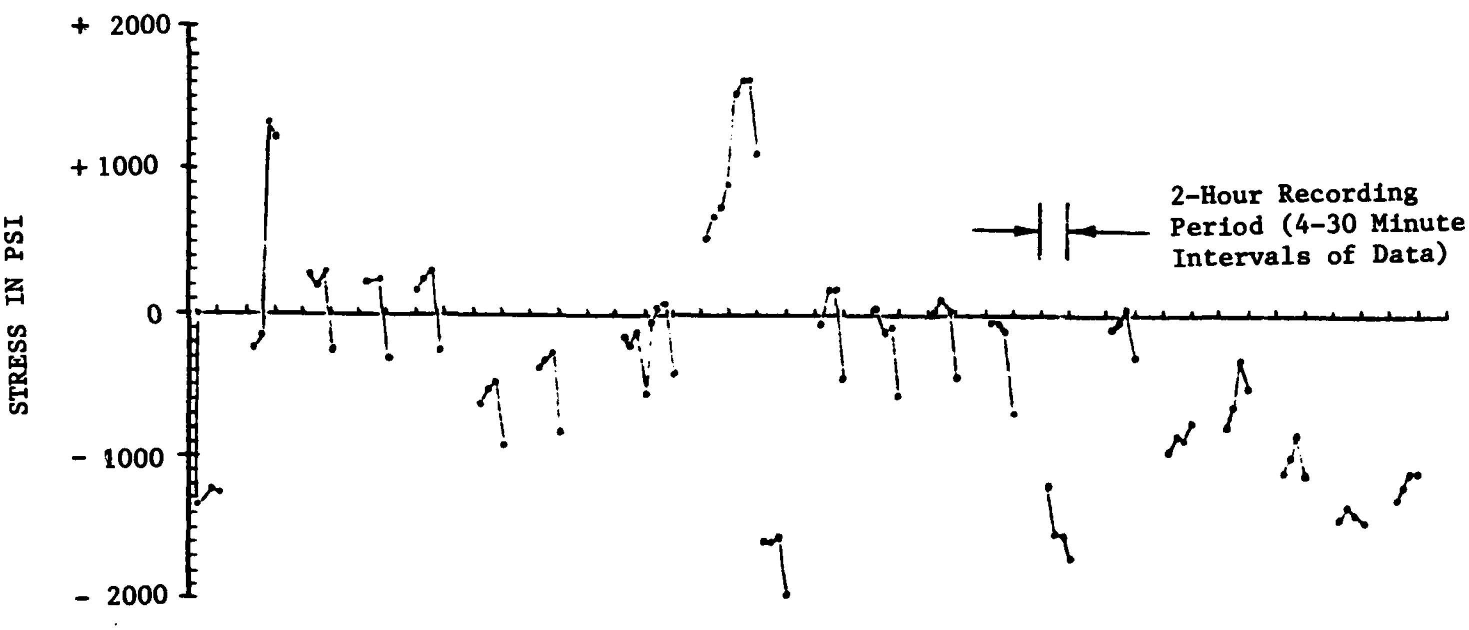
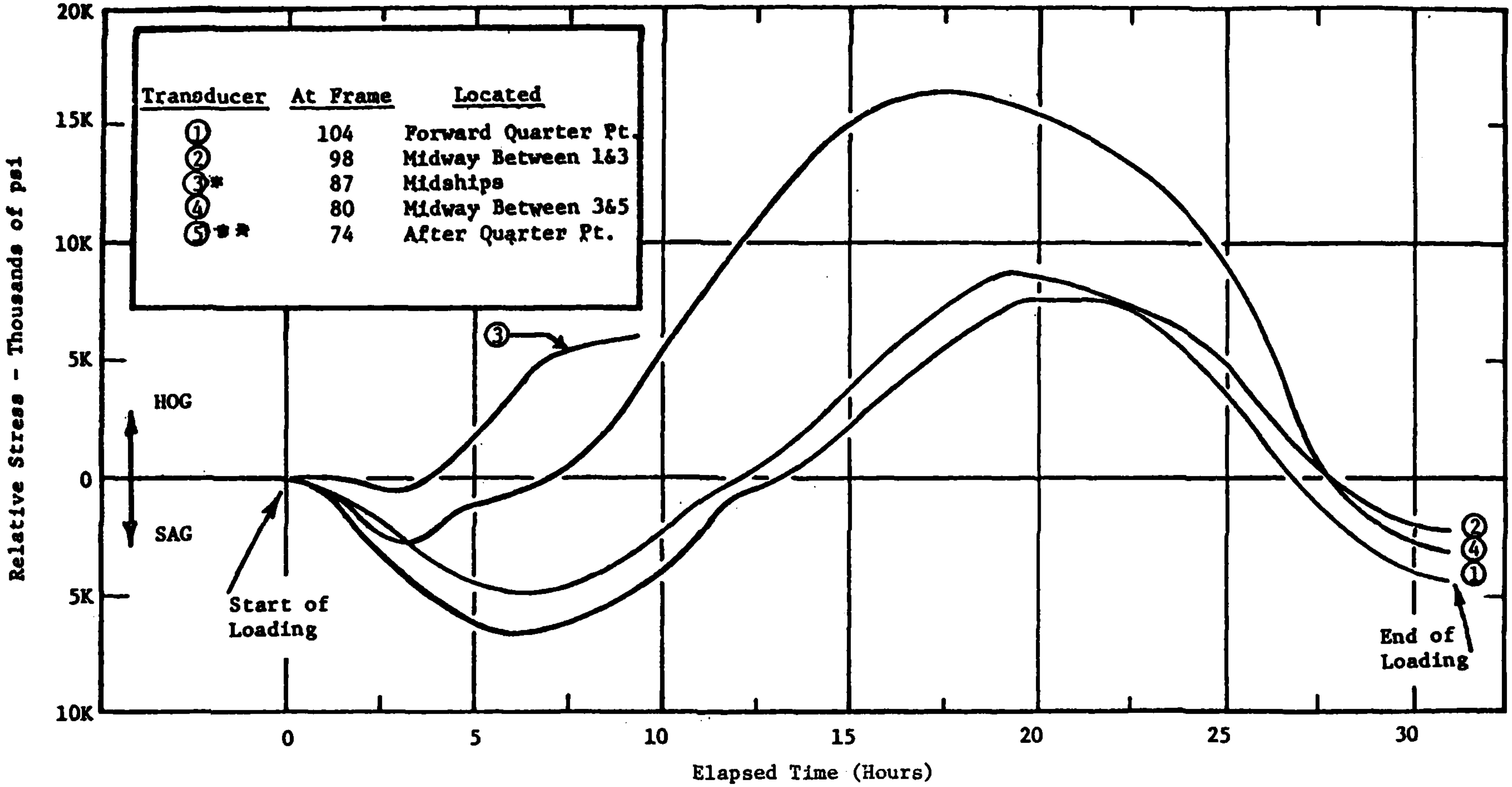


Figure 2-8

Varying Mean Stress Obtained on the SL-7
SEA-LAND McLEAN, First Half of Voyage 32W



* failed 9 hours after start

** inoperative

Figure 3-1

SS UNIVERSE IRELAND - Loading Crude Oil at Mina Al Ahmadi, Kuwait

Mid-Voyage 5, August 16 and 17, 1969

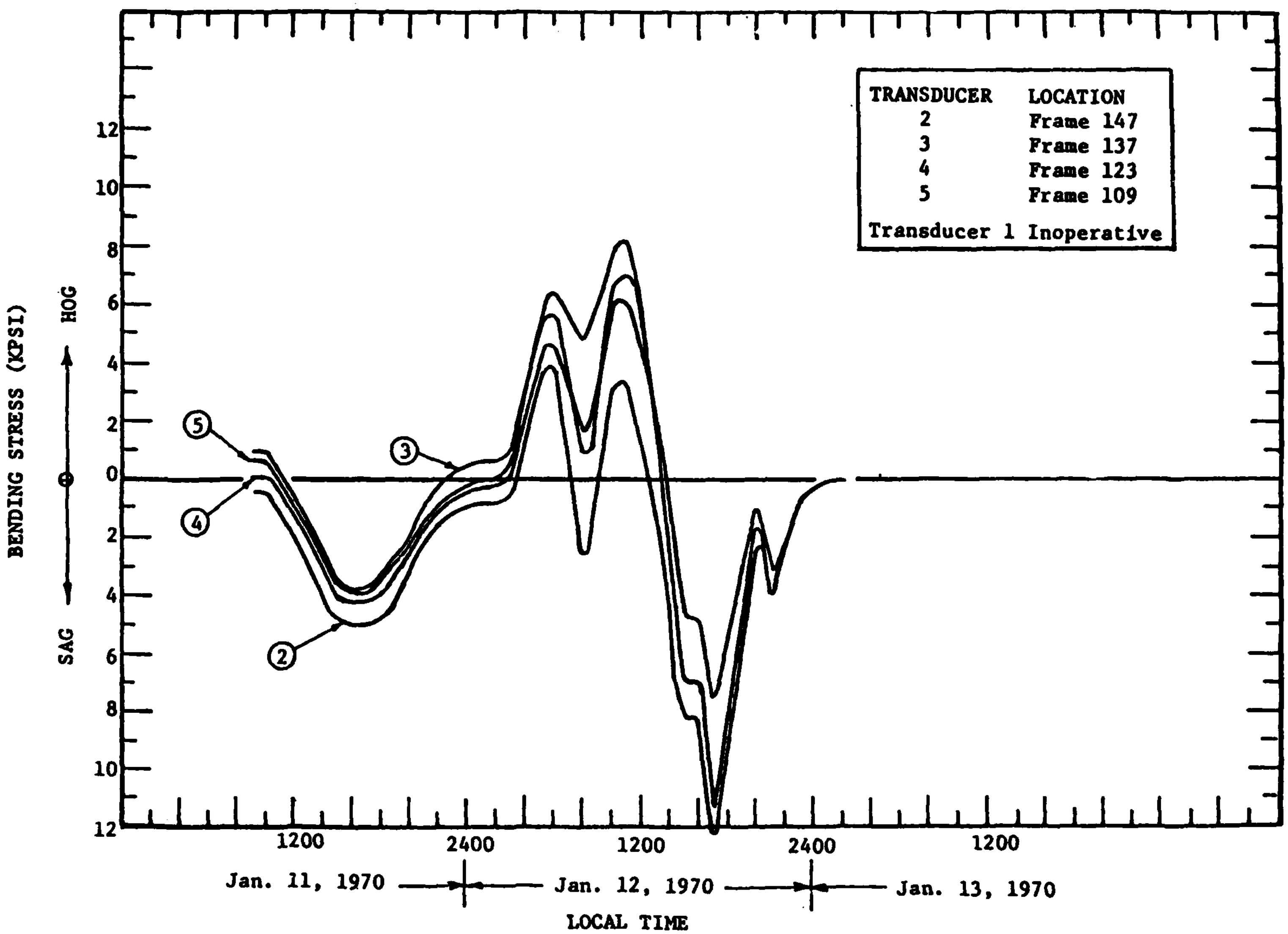


Figure 3-2

Bending Stress vs. Time, M/V FOTINI L Loading Iron Ore, San Nicolas, Peru; Mid-Voyage 15

(Reference 5)

the stress changes for the FOTINI L and UNIVERSE IRELAND are similar for each ship; however, the differences in the rates of change are surprisingly variable. Based on the design specifications, the magnitude of the loading stresses is somewhat higher than anticipated for the UNIVERSE IRELAND. The maximum permissible bending moment at midship (2,356,440 ft-tons) would induce a bending stress of about 9,250 psi. Loading stresses on the order of 12,000 to 14,000 psi consistently occur during loading and unloading and at locations distant from midship.

The stress variation patterns differ markedly between the FOTINI L and the UNIVERSE IRELAND as would be expected because of the variations in loading sequence and character of the particular cargo.

It is also interesting to note that the bulk carrier experiences several cycles of significant stress variation in contrast to the tanker where essentially one significant stress cycle occurs.

Midship stresses are presented in Figures 3-3 through 3-7 for five different vessels from a departure point to an arrival point. The plotted stresses are relative (referenced to a departure when the gauges were zeroed). The still water stress conditions were estimated for the fully loaded departure condition and presented in Table 3-1. The state of stress upon departure presented in Figures 3-3 through 3-7 represents the sum total stress experienced by the vessels. The solid dark line represents the average of the peak-to-trough wave-induced stress which is presumably equivalent to stresses caused by shifts in ballast, consumables and thermal effects as indicated in Section 2.2. The vertical spike lines represent the maximum peak-to-trough wave bending stresses for a given recording interval. The thermal stress variations are rather substantial for certain atmospheric conditions. The large change in ballast at sea is also apparent in Figures 3-3 through 3-7 as are the shifts from the consumption of fuel and other consumables.

3.2 VARIATION OF SWBM INDICATED BY LOADING MANUALS

In addition to the measured data it was felt it would be instructive to review the existing trim and stability books for recently built ship types to obtain a base knowledge of:

1. The maximum allowable SWBM in which the ship normally operates.
2. The variance of SWBM throughout the voyage.

An example of the influence lines approach (7) for the SL-7 class of containerships is presented in Figure 3-8. For this example, the moments are estimated, averaged and compared to an allowable SWBM-induced stress through a stress numeral as shown in Figures 3-9 and 3-10. The same system is used on the SL-7s to control the SWBM at sea. The SWBM is compared to an allowable SWBM through the stress numeral. For the SL-7s, the SWBM is also balanced against a stringent GM (transverse metacentric height) requirement and trim limitations.

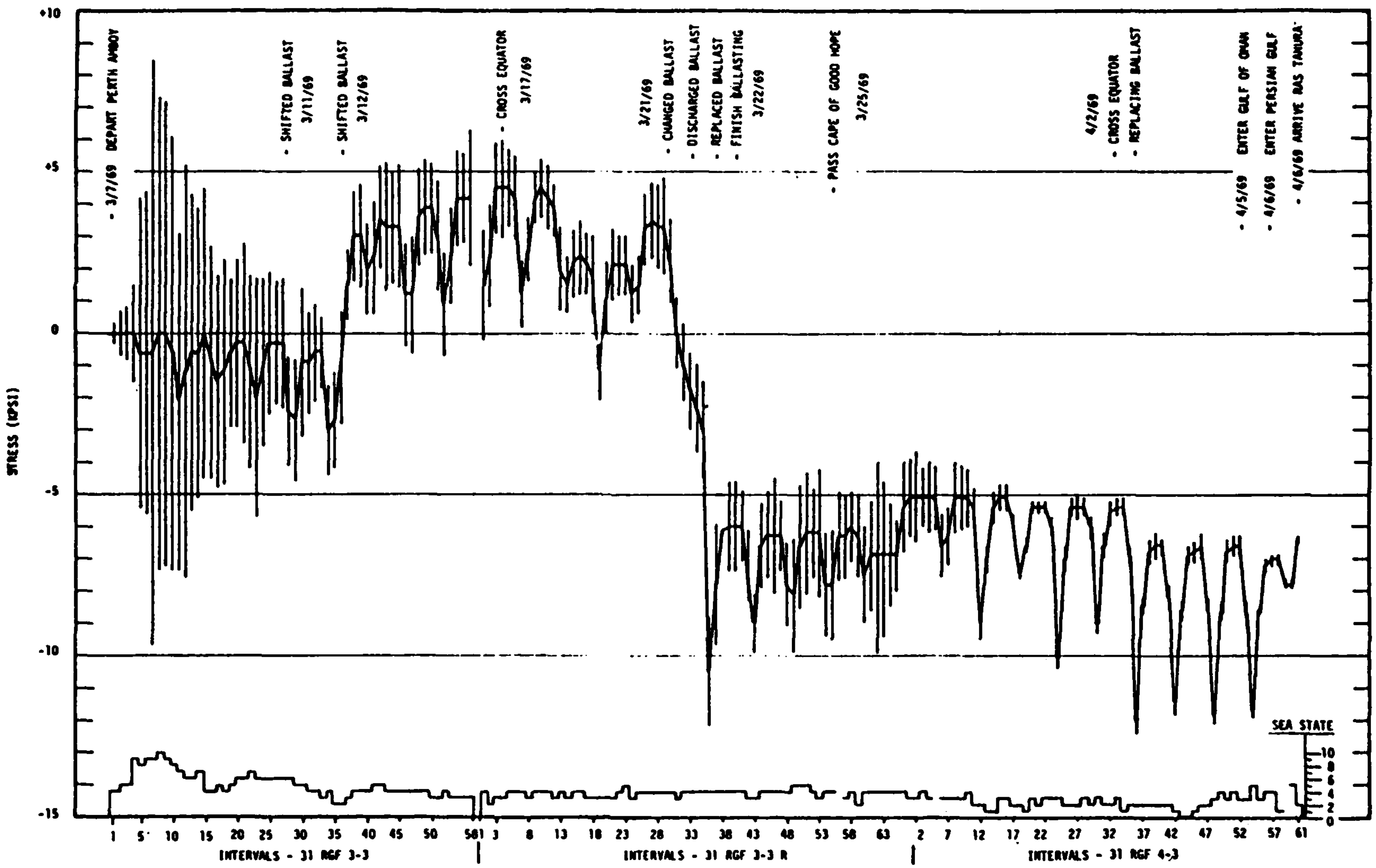


Figure 3-3

Midship Vertical Bending Stress Variations Throughout

First Leg of Voyage 31 of R.G. FOLLIS

(Reference 5)

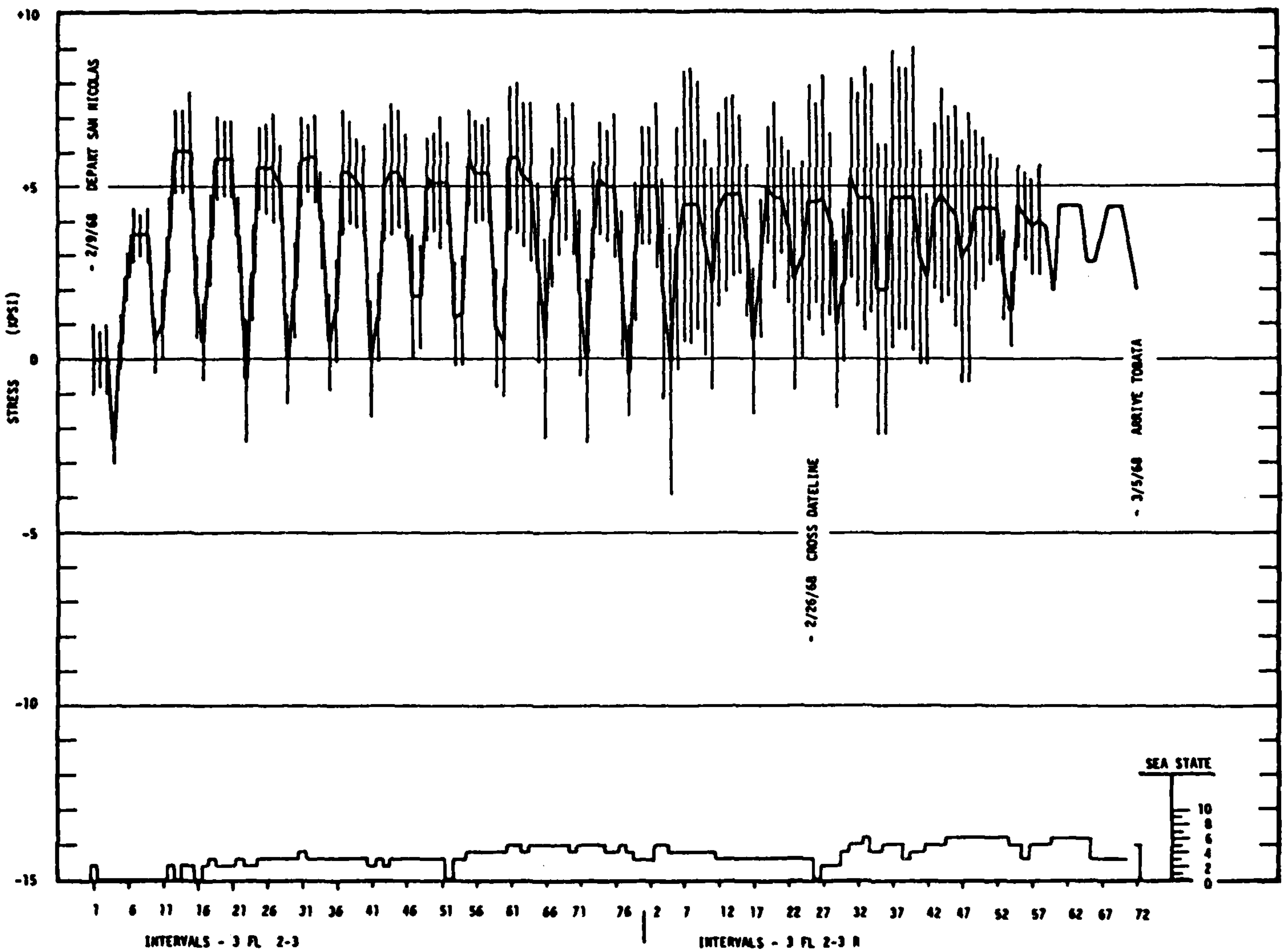


Figure 3-4

Midship Vertical Bending Stress Variations for Loaded Condition of Voyage 3 of FOTINI L

(Reference 5)

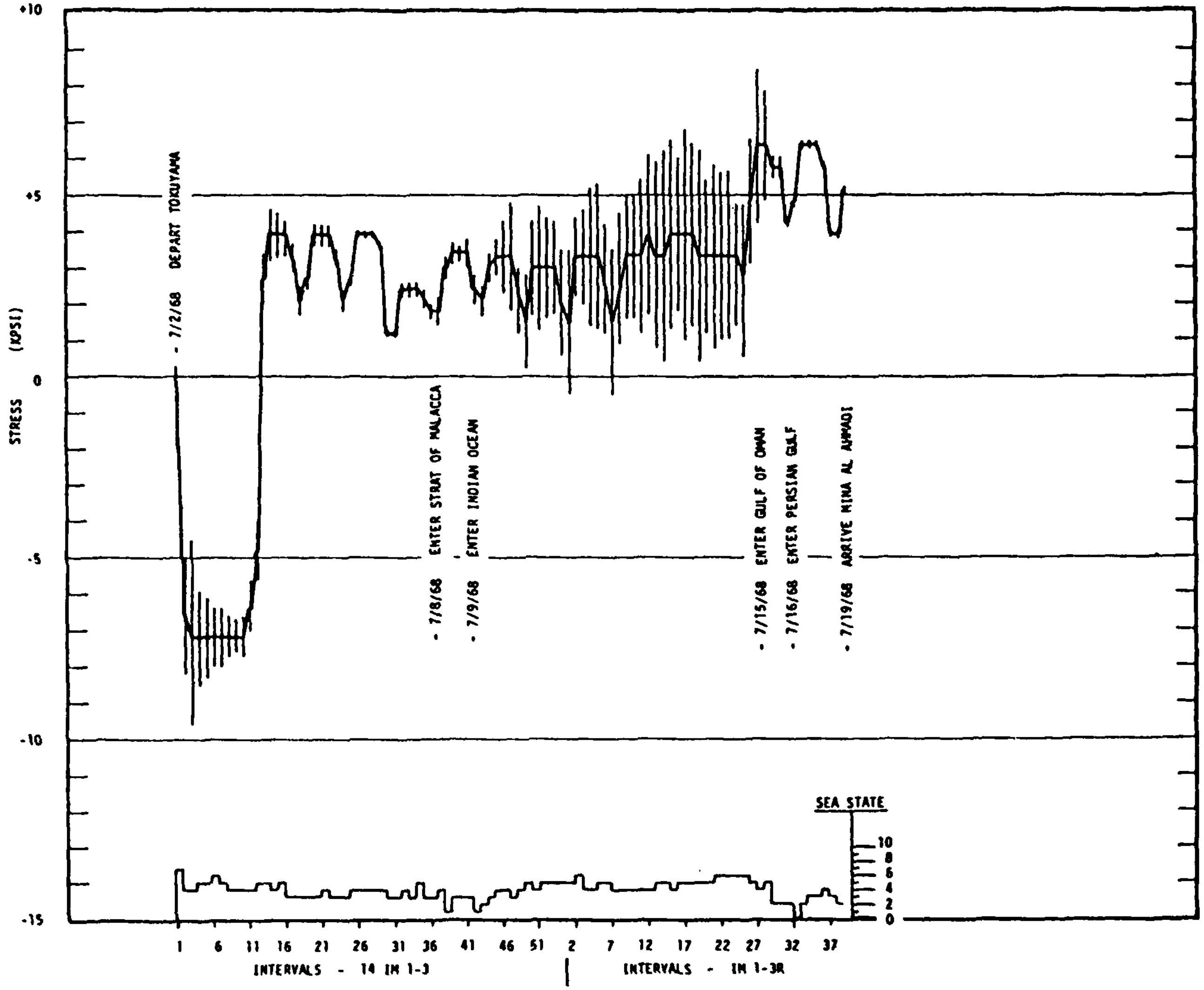


Figure 3-5

Midship Vertical Bending Stress Variations for Ballast Condition of Voyage 14 of IDEMITSU MARU

(Reference 5)

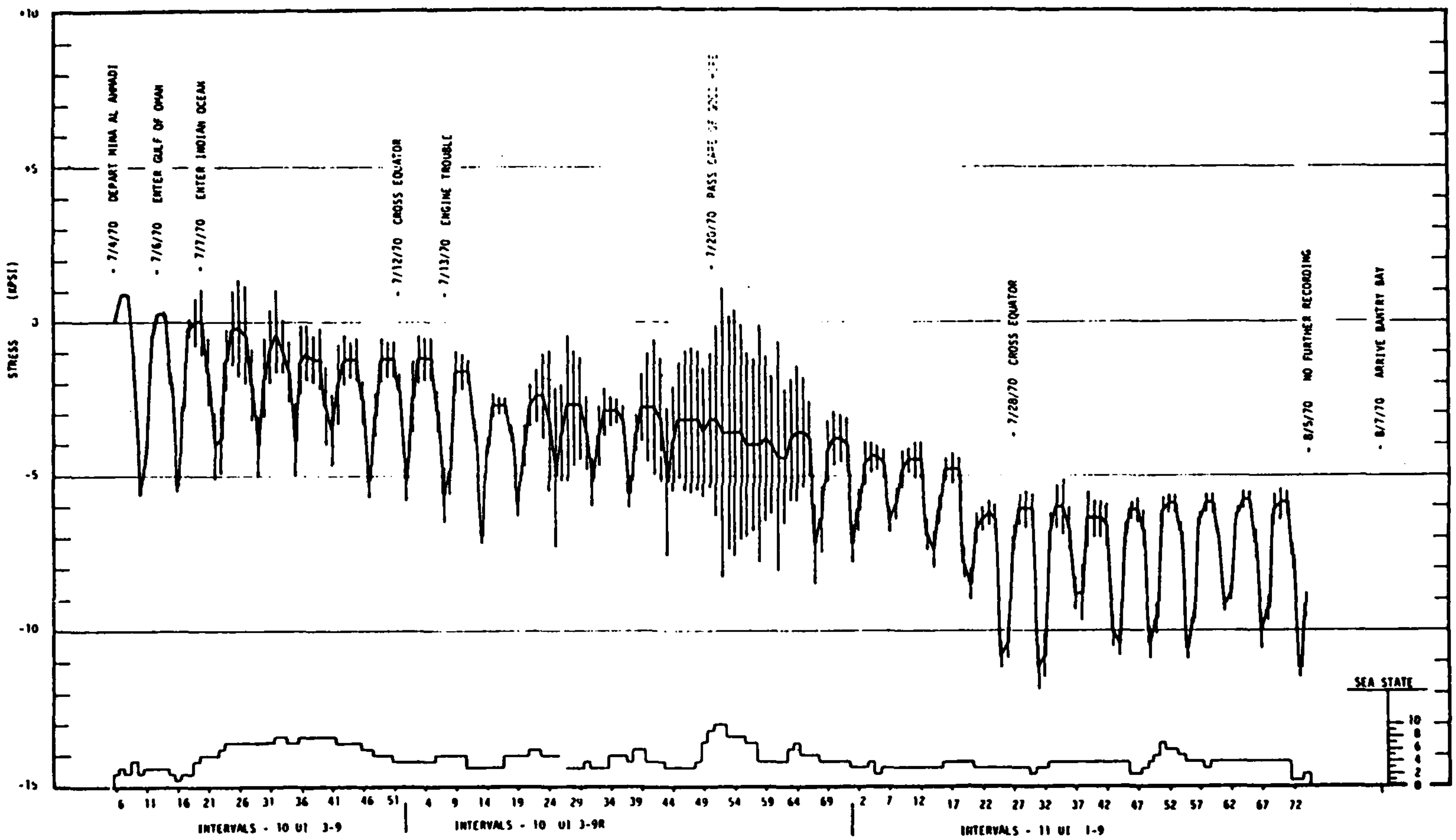


Figure 3-6

Midship Vertical Bending Stress Variations for Loaded Condition of Voyage 10 of UNIVERSE IRELAND

(Reference 5)

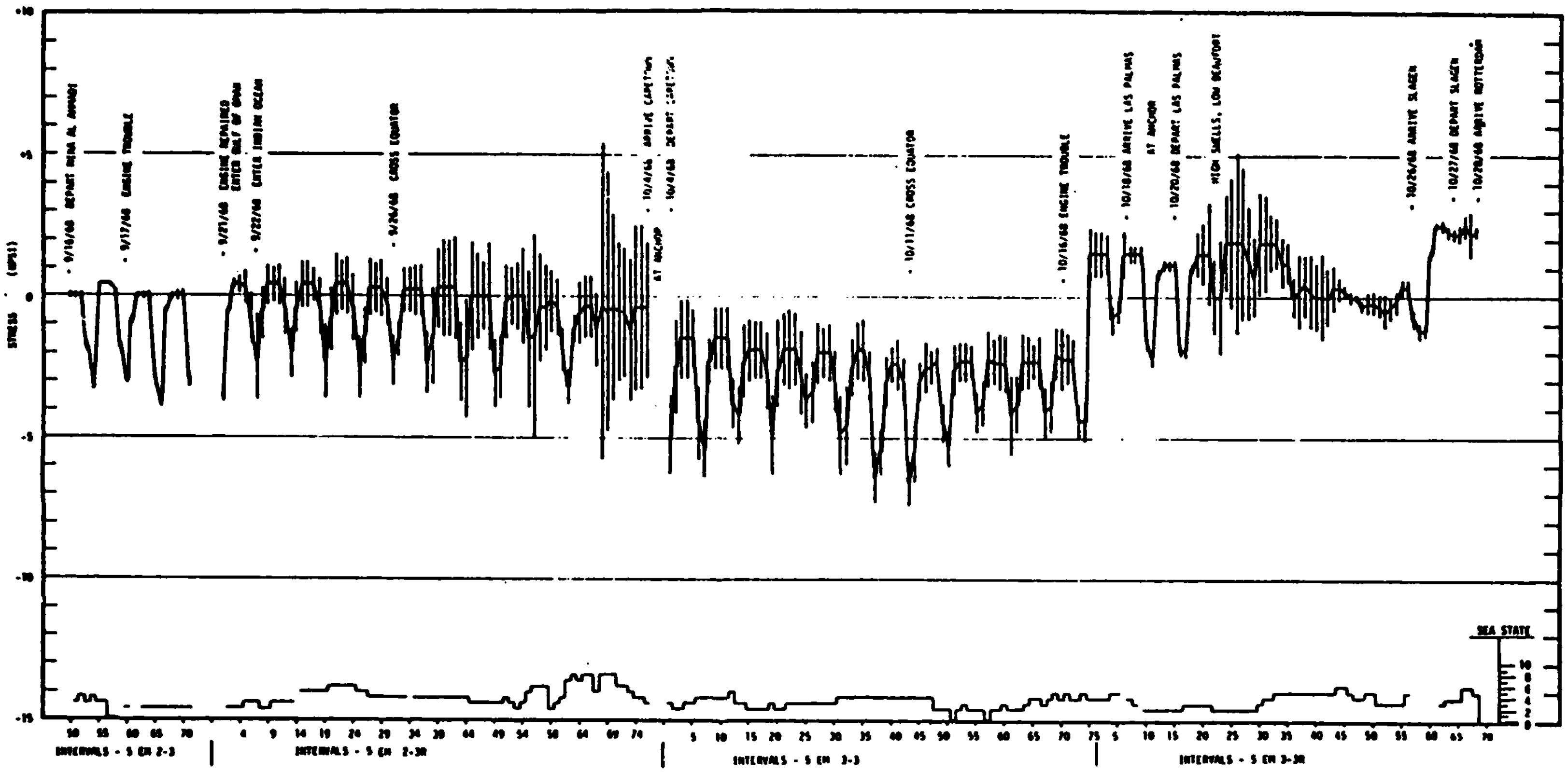


Figure 3-7

Midship Vertical Bending Stress Variations for Loaded Condition of Voyage 5 of ESSO MALAYSIA

(Reference 5)

TABLE 3-1

Departure-Arrival Stresses for Five Ships

	Full-Load Departure Midship Bending Stress	Arrival Midship Bending Stress	Change in Stress Between Departure And Arrival Conditions	Reference Figure
UNIVERSE IRELAND	-2,020 psi	- 9,720 psi	- 7,700 psi	3-6
IDEMITSU MARU	+1,000 psi	+12,700 psi	+11,700 psi	3-5
ESSO MALAYSIA	-5,200 psi	- 3,000 psi	+ 2,200 psi	3-7
R.G. FOLLIS	-1,000 psi*	- 7,300 psi	- 6,300 psi	3-3
FOTINI L	-1,100 psi	+ 3,200 psi	-14,300 psi	3-4

* Assumed value - no data

(Reference 5)

FUEL OIL CONSUMPTION AND BALLASTING RECORD FOR VOYAGE NO. ______

ROUTE Atlantic ______ CONDITION ______ COND. NO. ______

Col. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Item	Tank No.	Tons Prev.-New Tons Change	Draft Ft.	GM Summary (ft.) Avail. GM must be greater than req'd GM' Req'd	GM Avail.	Mod. to GM	LCG Ship LCG Tank	Long'l Mom. Ship Ft-ts Long'l Mom. Tank Ft-ts	Mean Mom. of Displ. one-half of Col. 8	* Stress Numeral	LCB Ft.	Trim Lever F/A Trim Moment	MT1" Trim T R F/A	Trim Fwd 0.565 T Trim Aft 0.435 T	Draft Fwd Draft Aft
Displacement		49,075	33.33	2.43	2.70		A 42.93	2,106,945	4,265,537	50	A 39.02	3.91A 191,883	6728 2.38	1.34 1.04	31.99 34.37
Fuel Oil Tank ~~Ballast Tank~~	DB8C	289 − 0 = −289				−0.22	A 155.78	−45,020	−22,510						
Displacement		48,786	33.18	2.45	2.48		A 43.19	2,061,925	4,243,027	57	A 38.88	4.31A 210,267	6699 2.62	1.48 1.14	31.70 34.32
~~Fuel Oil Tank~~ Ballast Tank	DB4P/S	0 + 506 = +506				+0.42	F 29.88	−15,179	+7,590						
Displacement		49,294	33.45	2.42	2.90		A 41.52	2,046,746	4,250,617	57	A 39.11	2.41A 118,798	6750 1.47	0.83 0.64	32.62 34.09
Fuel Oil Tank ~~Ballast Tank~~	DB3C	433 − 0 = −433				−0.33	F 112.75	+48,821	−24,411						
Displacement		48,861	33.22	2.45	2.57		A 42.89	2,095,567	4,226,206	55	A 38.92	3.97 193,978	6706 2.41	1.36 1.05	31.86 34.27
~~Fuel Oil Tank~~ Ballast Tank	DB2C	0 + 408 +408				+0.33	F 189.49	−77,312	+38,656						
Displacement		49,269	33.45	2.42	2.90		A 40.96	2,018,255	4,264,862	55	A 39.11	1.85A 91,148	6750 1.12	0.64 0.48	32.81 33.93
~~Fuel Oil Tank~~ Ballast Tank	DT5P/S	0 + 948 +948				+0.52	A 317.66	+301,142	+150,571						
Displacement		50,217	33.95	2.36	3.42		A 46.19	2,319,397	4,415,466	62	A 39.53	6.66A 334,445	6846 4.07	2.67 1.40	31.28 35.35
Fuel Oil Tank ~~Ballast Tank~~	DT1C	961 − 481 = −480				−0.25	F 355.93	+170,846	−85,423						
Displacement		49,737	33.71	2.39	3.17		A 50.07	2,490,243	4,330,043	57	A 39.33	10.74A 534,175	6800 6.55	3.70 2.85	30.01 36.56
~~Fuel Oil Tank~~ Ballast Tank	DB3P/S	0 + 218 = +218				+0.20	F 103.92	−22,655	+11,328						
Displacement		49,955	33.81	2.37	3.37		A 49.39	2,467,588	4,341,371	58	A 39.41	9.99A 499,050	6818 6.10	3.45 2.65	30.36 36.46
Fuel Oil Tank ~~Ballast Tank~~	DT1C	481 − 0 = −481				−0.24	F 355.93	+171,203	−85,602						

continued on the next page

Figure 3-8. Loading Manual for the SL-7 Class of Containerships Calculation of Moment at Sea (Reference 7)

Displacement		49,474	33.55	2.41	3.13		A 53.34	2,636,791	4,256,769	50	A 39.11	14.23A 704,015	6769 8.67	4.90 3.77	28.65 37.32
~~Fuel Oil Tank~~ Ballast Tank	DB9P/S	0 + 464 = + 464				+ 0.32	A 192.35	+ 89,250	+ 44,625						
Displacement		49,938	33.80	2.37	3.45		A 54.62	2,728,041	4,300,394	54	A 39.40	15.22A 760,056	6817 9.29	5.26 4.04	28.55 37.84
Fuel Oil Tank ~~Ballast Tank~~	DB9C	481 − 0 = − 481				− 0.34	A 192.80	− 92,737	− 46,369						
Displacement		49,457	33.54	2.42	3.11		A 53.20	2,635,304	4,254,025	50	A 39.20	14.08A 696,355	6767 8.76	4.65 3.91	28.69 37.45
Fuel Oil Tank ~~Ballast Tank~~	DB4C	434 − 0 = − 434				− 0.33	F 32.75	+ 14,214	− 7,107						
Displacement		49,023	33.30	2.43	2.78		A 54.05	2,649,518	4,246,918	56	A 38.99	15.06A 738,286	6722 9.15	5.17 3.98	28.13 37.28
~~Fuel Oil Tank~~ Ballast Tank	DB1C	0 + 141 = + 141				+ 0.12	F 252.20	− 35,571	+ 17,786						
Displacement		49,164	33.38	2.42	2.90		A 53.17	2,613,947	4,264,704	57	A 39.05	14.12A 694,196	6718 8.61	4.67 3.74	28.51 37.32
Fuel Oil Tank ~~Ballast Tank~~	DB5C	486 − = − 318				− 0.25	A 52.21	− 16,603	− 8,301						
Displacement		48,846	33.21	2.42	2.65		A 53.17	2,597,343	4,256,403	57	A 39.00	14.17A 692,146	6704 8.60	4.86 3.74	28.35 36.95
Fuel Oil Tank Ballast Tank															
Displacement															
Fuel Oil Tank Ballast Tank															
Displacement															
Diesel Oil and Fuel Additive		-78				-0.03		-18,892	-9,446						
Fresh Water		-112				+0.05		+10,612	-5,306						
Total		48,656	33.10	2.46	2.65		A 53.21	2,589,063	4,241,651	57	A 38.82	14.39A 700,160	6685 8.73	4.93 3.80	20.17 36.90

Longitudinal centers and moments of displacement are + when forward of midships and - when aft
For signs of tank moments, see diagram on page 11
* For required GM, see page 17
\# For gain or loss in GM, see page 11
\# For Stress Numeral, see page 7

Figure 3-8 (Cont.) Loading Manual for the SL-7 Class of Containerships Calculation of Moment at Sea (Reference 7)

Sea-Land Service, Inc. Route Atlantic	Trim, Stability and Longitudinal Strength	SL-7 Vessels Condition: Departure

Part 4 — Summary

SUMMARY

Symbol	Tons	Vertical C.G.	Vertical Moment	Aft C.G.	Aft Moment	Forward C.G.	Forward Moment	Mom F.S
Containers	18.608	54 49	1,013,931		1,807.647		1,073,978	
Cargo Holds								
Fuel Oil	4,036	15.03	60,661		281.550		405.084	15.387
Ballast Water	1,046	14.78	15.456		66.466		253.805	
Diesel Oil & Fuel Add	138	19.52	2,694	242 21	33.425			88
Fresh Water	576	22.56	12.997		71.481		21.983	195
Mud (in Light ship)								
Deadweight, Sub-Total	24.404		1,105.739	(1)	2,080.569	(2)	1,754.850	
Deadweight Moment, total					305.719			
Operating Light Ship w/Mud	24.671	38 37	946.704	73.01	1.801.226			1.598
Displacement	49.075	41.82	2.052.443	42 93	2.106.945			17.268

TRIM				
L C F	— 61 05 ft	Draft at L.C F		33.33 ft
L C.B	— 39 02 ft	Trim at F P		1.34 ft
L C G	— 42.93 ft	Trim at A P		1 04 ft
Trimming Lever (AFT)	3.91 ft	DRAFTS	F P	31.99 ft
Moment to Trim 1"	6.728 ft-ts		A.P	34 37 ft
Trim between, Perpendiculars	2 38 ft		mean	33.18 ft

STRESS NUMERAL		
(1)	Total Aft Deadweight Moment, ft-tons (From Summary Above)	2,080.569
(2)	Total Forward Deadweight Moment (From Summary Above)	1,754.850
(3)	Total Forward and Aft Deadweight Moment (1) + (2)	3,815.419
(4)	Mean Deadweight Moment [one-half of line (3)]	1,907.710
(5)	Mean Moment of Light Ship (Constant)	2.357.827
(6)	Mean Moment of Displacement (4) + (5)	4.265.537
(7)	Stress Numeral from page 21	50

STABILITY			
Metacenter above B L = KM	44 87 ft	Free Surface Moment	17.268 ft-ts
V C G = KG	41 82 ft	Allowance for Free Surface	0.35 ft
Metacentric Height = GM	3 05 ft	GM corrected	2.70 ft
		GM required	2.43 ft

Angle of Inclination = Ø	10°	20°	30°	45°	60°	75°
sin Ø	0 174	0 342	0 500	0.707	0 866	0.966
Uncorrected Righting Arm (Tables) = Y	7 84	15 79	23 86	34.17	39 46	41 10
KG (from V C G above)	41 82	41 82	41 82	41 82	41.82	41 82
Free Surface addition	0 35	0.35	0 35	0.35	0 35	0.35
Virtual KG	42 17	42 17	42 17	42.17	42.17	42 17
KG sin Ø	7 33	14 42	21 09	29.81	36.52	44 74
Corrected Righting Arm = Y-KG sin Ø	0 51	1 37	2.77	4 36	2.94	0 36

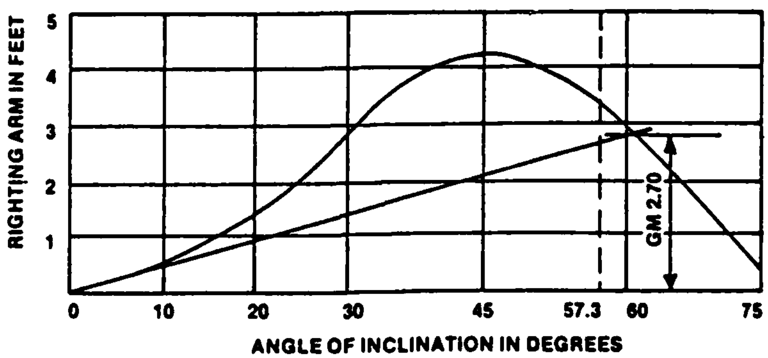


Figure 3-9

Loading Manual for the SL-7 Class of Containerships
Calculation of Loading Moment for a Departure Condition
(Reference 7)

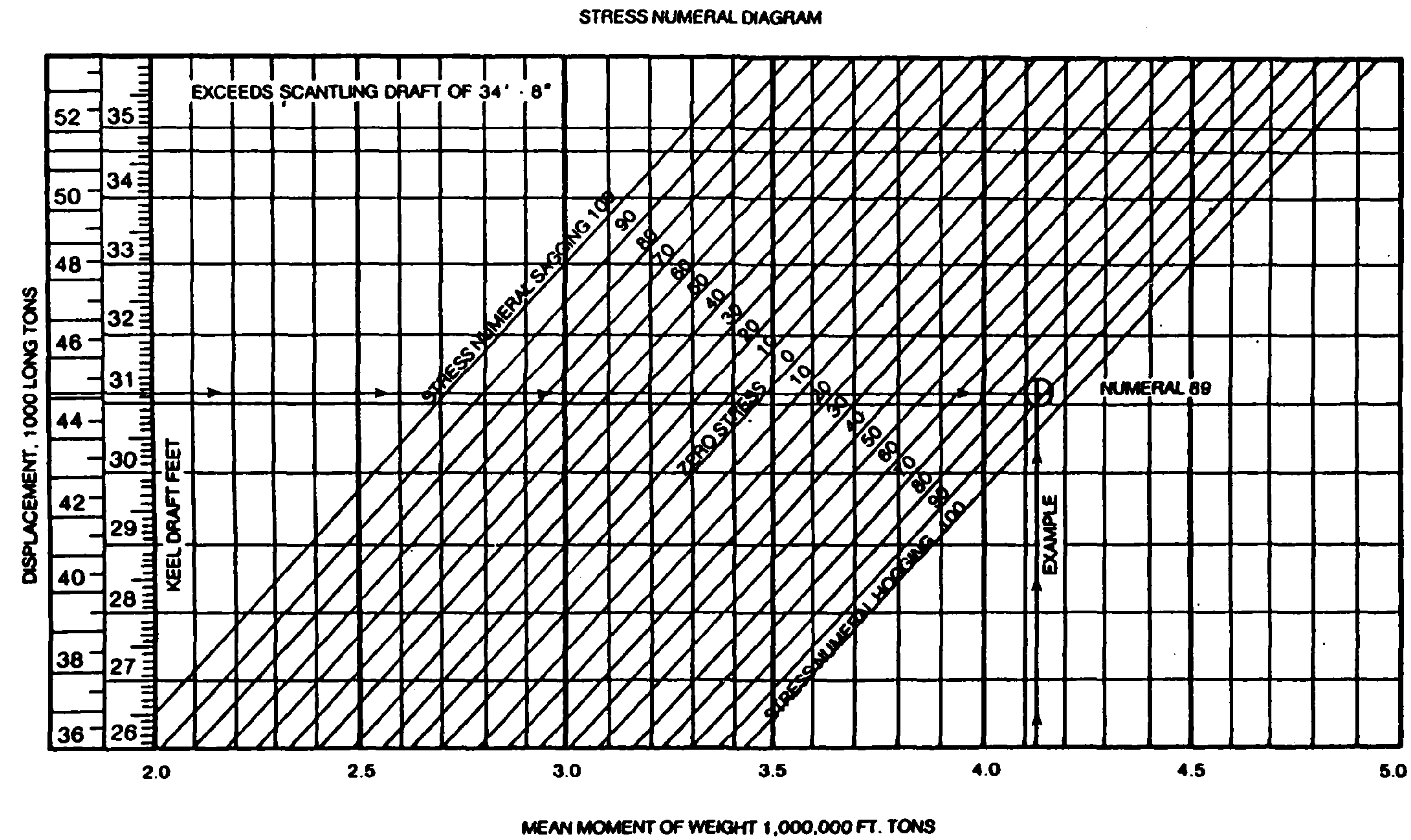


Figure 3-10 Loading Manual for the SL-7 Class of Containerships
Stress Numeral Diagram
(Reference 7).

Typical loading conditions as developed for loading manuals are presented in Tables 3-2 through 3-5 (2) for the SL-7 SEA-LAND McLEAN (containership), FOTINI L (dry-bulk carrier) and the UNIVERSE IRELAND (tanker). The manual method for calculation of the SWBM as indicated in the samples for loading manuals are similar. The loaded cargo moments are summed, averaged and added to light ship bending moments. The total SWBM is then compared to a maximum allowable SWBM or SWBM-induced stress, depending on the preference of those preparing the manuals. For the SL-7 SEA-LAND McLEAN, the SWBM-induced stress is compared to the allowable stress through a numeral which is actually a percent of the allowable stress.

The loading manual for the LNG FRANCE DUNKERQUE (8) contains plots of typical loading conditions, weight, buoyancy and bending moment as a function of ship length as shown in Figures 3-11 and 3-12. Loading schemes 2 and 3 presented different bending moment curves caused by the addition of 1000 tons of ballast located in a forward tank. The result is a large longitudinal shift (approximately 100 meters) in the location of maximum SWBM.

It should be noted that in each manual method for estimating SWBM presented here the bending moment amidships is the only moment predicted. Unless the original calculations considered all possible loading conditions and the magnitude of bending moment (BM) along the length of the vessel, it would be possible to be within the limits of midship SWBM, but to exceed SWBM limits elsewhere.

Similarly, any instrumented (strain gauge) system would have to utilize a series of strain gauges at predetermined critical points to accurately portray the maximum SWBM.

3.3 RECOMMENDATION OF SHIP TYPES TO BE INCLUDED FOR STATISTICAL CHARACTERIZATION OF SWBM

The ship types included in the previous studies would provide impetus for continuation of SWBM research on similar ship types. Other considerations, however, should influence the selection of ship types for further study. These include recent inputs from discussions with ship owners and operators.

Discussions with ship owners and operators indicated that tankers are experiencing large variations in SWBM from current segregated ballast requirements imposed by International Maritime Organization (IMO) regulations. Additional information was received indicating that older U.S. tankers may operate at very high SWBM due to reconfiguration to clean ballast tankers to meet the IMO regulations. The IMO and SWBM requirements limit cargo deadweight in many instances which could be especially significant for older, modified tankers. This deadweight restriction could provide additional incentive for ship owners and operators to become involved in the SWBM project when implementation is scheduled.

Table 3-2. SL-7, Summary of Sample Loading Conditions from Loading Manual

STILL WATER BENDING MOMENTS CALCULATIONS

Item \ Condition	Unit	ATLANTIC				PACIFIC			
		East Bound		West Bound		East Bound		West Bound	
		Depart New York	Arrive Europe	Depart Europe	Arrive New York	Depart Japan	Arrive U.S.A	Depart U.S.A	Arrive Japan
Displacement	LT	48504	47621	47880	46049	45112	41695	50374	49825
Light Ship Weight	LT	24671	24671	24671	24671	24671	24671	24671	24671
Dead Weight	LT	23833	22950	23209	21378	20441	17025	25703	25154
Containers	LT	18477	18477	17853	17833	12803	12803	18836	18836
Fuel Oil	LT	4036	1120	4036	1120	4998	948	4998	948
Diesel Oil	LT	138	60	138	60	138	60	138	60
Ballast	LT	606	2829	606	1881	1926	2750	1155	4846
Fresh Water	LT	576	464	576	464	576	464	576	464
Draft-Fore	FT	32.31	28.63	32.33	29.66	29.90	28.76	31.52	31.59
Draft-Aft	FT	33.56	35.55	32.95	33.24	32.13	29.62	35.97	35.48
Draft-Mean	FT	32.94	32.09	32.64	31.45	31.02	29.19	33.75	33.54
Trim	FT	1.25	6.92	0.62	3.58	2.23	0.86	4.45	3.89
Dead Weight Moment	LT-FT	1921494	1843776	1850450	1634112	1748750	1446084	2206986	2189014
Light Ship Moment	LT-FT	2357827	2357827	2357827	2357827	2357827	2357827	2357027	2357827
Disp. Moment	LT-FT	4279321	4201603	4208277	3991939	4106577	3803911	4564813	4546841
Stress Numeral		71	71	70	60	89	87	91	94
Buoy. Moment Hog	LT-FT	3731000	3590000	3602000	3535000	3450000	3155000	3875000	3835000
Net Buoy Moment	LT-FT	548320	611603	606277	456939	656577	648911	689813	711841
Stress	PSI	8388	9360	9280	6996	10045	9927	10554	10807
GM Corrected	FT	3.23	2.93	3.66	2.91	5.72	3.57	2.59	2.56
GM Required	FT	2.29	2.35	2.33	2.46	2.53	2.83	2.17	2.20

Section Modulus 184,521 IN^2 FT

(Reference 2)

Table 3-3. FOTINI L Summary of Sample Loading Conditions from Loading Manual

Item \ Condition	Unit	Heavy Cargo S.F. 20 €/LT				Coal Cargo S.F. 42 €/LT				Coal Cargo S.F. 48 €/LT			
		2	3	4	5	6	7	8	9	10	11	12	13
		Dep.	Arr.	Dep.	Arr.	Dep.	Arr.	Dep.	Arr.	Dep.	Arr.	Dep.	Arr.
Constants	LT	527	527	527	527	527	527	527	527	527	527	527	527
Provisions	LT	10	2	10	2	10	2	10	2	10	2	10	2
Fuel Oil	LT	2170	435	1339	226	2170	435	1339	226	2170	435	1339	226
Diesel Oil	LT	174	34	108	21	174	34	108	21	174	34	108	21
Fresh Water	LT	252	181	252	181	252	181	252	181	252	181	252	181
Ballast Water	LT	-	1950	-	1015	-	1920	1000	2015	1005	-	480	-
Cargo	LT	71070	71070	71967	71967	70509	70509	70509	70509	61696	61696	61696	61696
Deadweight	LT	74203	74199	74203	73939	73642	73608	73745	73481	65834	62875	64412	62653
Light Ship	LT	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950
Displacement	LT	90153	90149	90153	89889	89592	89558	89695	89431	81784	78825	80362	78603
Equiv. Draft	FT-IN	44-6½	44-6½	44-6½	44-5	44-3½	44-3¼	44-4	44-2½	40-8¼	39-3½	40-¼	39-2¼
Draft-Fore	FT-IN	44-6¼	44-6½	44-6¼	44-5	44-3	44-3¼	44-4	44-2¼	40-8¼	39-3¼	40-¼	39-3
Draft-Aft	FT-IN	44-6⅝	44-6½	44-6½	44-5	44-4	44-3¼	44-4	44-2½	40-8¼	39-3¾	40-¼	39-1⅝
Draft-Mean	FT-IN	44-6½	44-6½	44-6½	44-5	44-3½	44-3¼	44-4	44-2½	40-8¼	39-3½	40-¼	39-2⅜
Trim	FT-IN	0-⅛	0	0	0	0-1	0	0	0	0	0-⅝	0	0-1⅜
Max SWBM	LT-FT	175000	173000	-155000	156600	-286100	-290600	-306800	-277800	-100800	-156900	-139500	-149800
Max SWB stress	PSI	2473	2444	-2190	2213	-4042	-4106	-4335	-3925	-1424	-2217	-1971	-2217

€ = cubic feet
(+) Hogging
(-) Sagging

Section Modulus = 158576 IN^2-FT

(Reference 2)

Table 3-4. FOTINI L Summary of Sample Loading Conditions from Loading Manual

Item \ Condition	Unit	Bauxite S.F. 32 €/LT		Ballasted Condition			Ballast Condition			Summary from MARKA-L's Captain Abstract: Loaded Long Voyage		Summary from MARKA-L's Captain Abstract: Loaded Short Voyage		
		14	15	16	17	13	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Mean
		Dep.	Arr.	Dep.	Arr.	Arr.	Dep.	Dep.	Dep.	Dep.	Dep.			
Constants	LT	527	527	527	527	527	420	420	420	420	420	420	420	420
Provisions	LT	10	2	10	2	2								
Fuel Oil	LT	305	59	3905	2170	266	2663	640	553	1923	920	362	838	372
Diesel Oil	LT	25	5	314	174	21	148	74	100	105	83	68	29	93
Fresh Water	LT	252	181	252	181	181	30	60	50	30	100	20	50	30
Ballast Water	LT	-	305	34721	34721	34721	27000	26700	27553	-	-	-	-	-
Cargo	LT	73084	73084	-	-	-	-	-	-	69111	68713	61428	60590	61200
Deadweight	LT	74203	74163	39729	37775	35718	30261	27894	28676	71589	70236	62298	61927	62105
Light Ship	LT	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950	15950
Displacement	LT	90153	90113	55679	53725	51668	46211	43844	44626	87539	86186	78248	77877	78055
Equiv. Draft	FT-IN	44-6$\frac{1}{2}$	44-6$\frac{1}{4}$	28-3$\frac{1}{2}$	27-4	26-4$\frac{1}{4}$	-	-	-	-	-	-	-	-
Draft-Fore	FT-IN	44-6$\frac{1}{2}$	44-6$\frac{1}{4}$	23-2$\frac{3}{8}$	25-1$\frac{1}{2}$	26-0$\frac{1}{4}$	22-6	18-5	20-6	43-6	43-5	38-11	38-5	38-8
Draft-Aft	FT-IN	44-6$\frac{1}{2}$	44-6$\frac{1}{4}$	33-7$\frac{1}{4}$	29-7$\frac{3}{4}$	26-8$\frac{5}{8}$	28-6	27-9	27-4	44-8	43-10	39-10	39-3	39-8
Draft-Mean	FT-IN	44-6$\frac{1}{2}$	44-6$\frac{1}{4}$	28-5	27-4$\frac{3}{8}$	26-4$\frac{1}{2}$	25-6	23-1	23-11	44-1	43-7	39-4	38-10	39-2
Trim	FT-IN	0	0	10-4$\frac{1}{2}$	4-6	0-8$\frac{1}{2}$	6-0	9-4	6-10	1-2	0-5	0-11	0-10	1-0
Max. SWBM	LT-FT	-228600	-232500	266700	213100	198600	227112	238867	-176133	-366571	-	-	-	-116882
Max SWB Stress	PSI	-3230	-3285	3768	3011	2806	3209	3375	-2488	-5179	-	-	-	-1651

(+) Hogging
(-) Sagging

(Reference 2)

Table 3-5. UNIVERSE IRELAND Summary of Sample Loading Conditions from Loading Manual

Condition / Item	Unit	Full Load (Summer) Long Voyage				Full Load Short Voyage		Dirty Ball.	Normal Ballast		Heavy Ballast		Bet. 8&9
		2	3	4	5	6	7	8	9	10	11	12	13
		Dep.	Arr.	Dep.	Arr.	Dep.	Arr.	Dep.	Dep.	Arr.	Dep.	Arr.	Dep.
Constants	LT	-	-	-	-	-	-	-	-	-	-	-	-
Provisions	LT	-	-	-	-	-	-	-	-	-	-	-	-
Fuel Oil	LT	12943	6707	12943	6707	4895	2855	6707	6707	1118	6707	1118	6707
Diesel Oil	LT	-	-	-	-	-	-	-	-	-	-	-	-
Fresh Water	LT	605	248	605	248	363	232	605	605	248	605	248	605
Ballast Water	LT	-	-	-	-	-	-	-	28370	29530	33378	33378	26000
Cargo	LT	312702	312702	312702	312702	320992	320992	145469	45388	50174	86661	92607	34554
Deadweight	LT	326250	319657	326250	319657	326250	324079	152781	81070	81070	127351	127351	67866
Light Ship	LT	49561	49561	49561	49561	49561	49561	49561	49561	49561	49561	49561	49561
Displacement	LT	375811	369218	375811	369218	375811	373640	202342	130631	130631	176912	176912	117427
Draft-Fore	FT-IN	81-5	80-1	80-7 1/8	80-1	81-5	81-2 5/8	37-8 1/4	27-10 3/4	28-1 1/2	37-1	38-1/2	20-8 3/8
Draft-Aft	FT-IN	81-5	80-1	82-3 1/4	80-1	81-5	80-8 7/8	54-1/2	32-9	32-5 7/8	43-10 3/8	42-5 1/2	34-8 1/2
Draft-Mean	FT-IN	81-5	8[illegible]-1	81-5 1/2	80-1	81-5	80-11 3/4	45-10 3/8	30-3 7/8	30-3 3/4	40-5 3/4	40-3	27-8 1/2
Trim	FT-IN	0	0	1-8 1/8	0	0	F0-5 3/4	16-4 1/4	4-10 1/4	4-4 3/8	6-9 3/8	4-5	14-0 1/8
Max SWBM	LT-FT*	-1050	-1940	-770	-1790	-2220	-2355	-1960	1858	1640	-1709	-1770	-2017
Position	FR.NO.	107	84	108	82	81	80	100	80	83 1/2	101 1/2	101	98
Max.SWB Stress	PSI	-4150	-7667	-3043	-7074	-8774	-9307	-7746	-7343	6481	-6718	-6995	-7971

Section Modulus = 566,794 $FT\text{-}IN^2$

(+) Hogging
(-) Sagging
(*) Times 10^{-3}

(Reference 2)

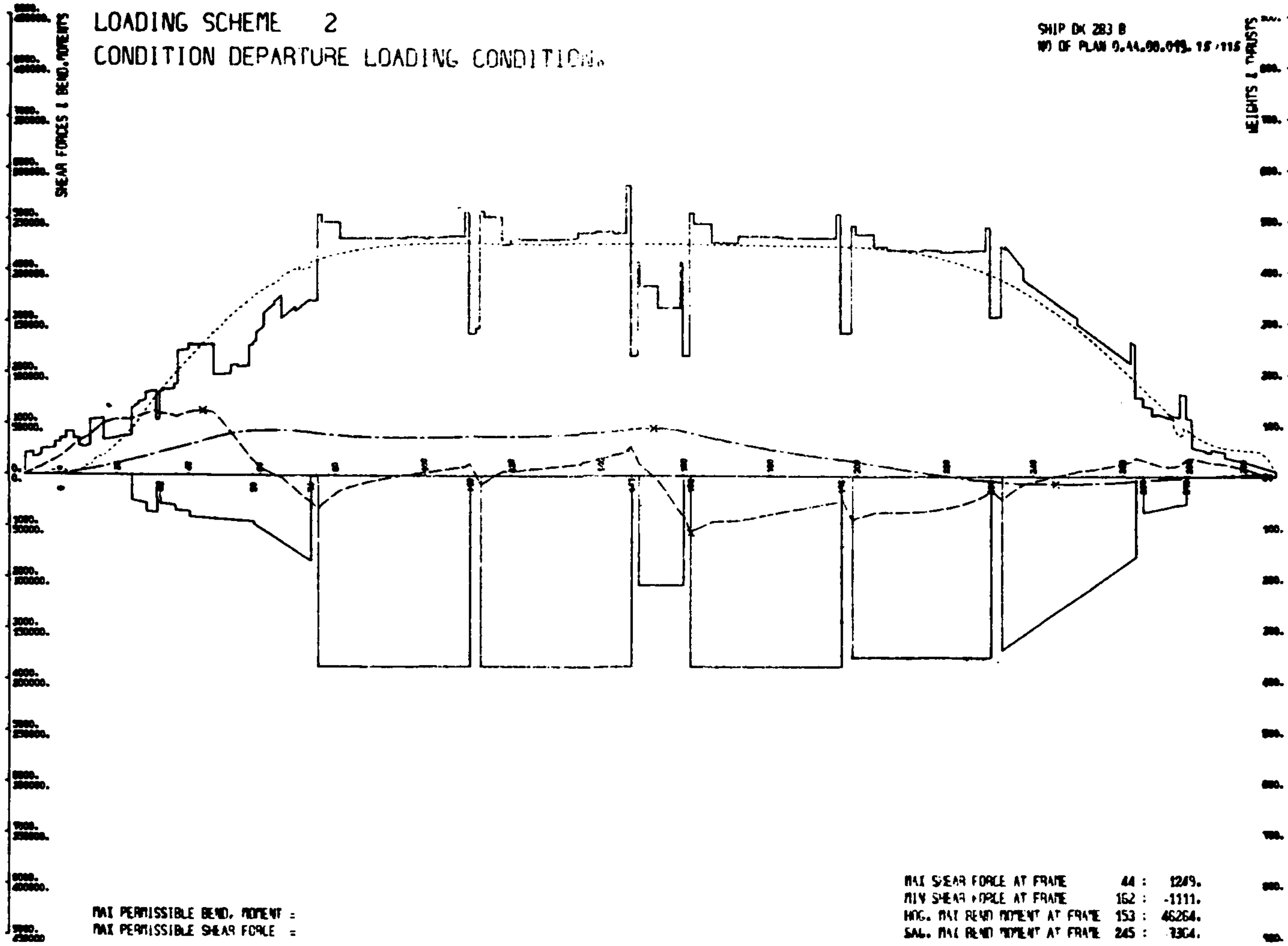


Figure 3-11 Loading Scheme 2 for the LNG FRANCE DUNKERQUE

(Reference 8)

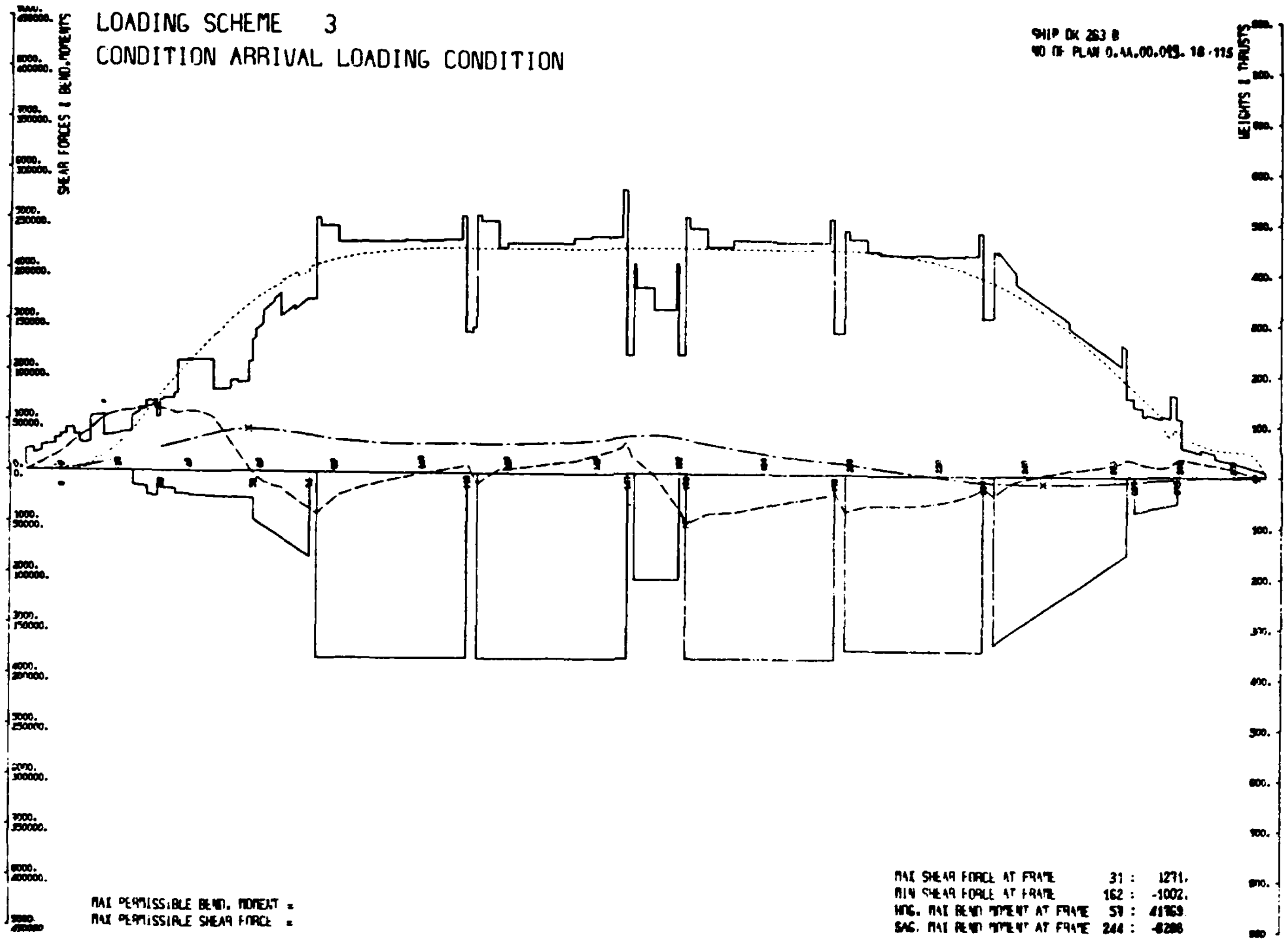


Figure 3-12 Loading Scheme 3 for the LNG FRANCE DUNKERQUE

(Reference 8)

As a result of the investigation of SWBM variations and interviews with ship owners and operators, the following list of ship types has been drawn up with a descending priority of the types to be included in the study:

1. Tankers
2. Bulk carriers (including Great Lakes vessels)
3. Barge carriers
4. Container ships
5. LNG, LPG and chemical carriers
6. General cargo ships
7. Heavy lift ships
8. Car carriers, passenger ships and ferries

Based on our investigation, at least the first five ship types in this listing should be considered active candidates for this study. The ordering priority, however, may change as ship availability becomes firm upon implementation of the SWBM test plan.

4.0 EVALUATION OF VARIOUS METHODS OF DETERMINING SWBM

We have determined that there are three methods of obtaining SWBM data, as follows:

1. Manual calculation records
2. Loading computer records
3. Instrumentation

In the following sections we will describe the advantages, disadvantages and costs of each of these methods.

4.1 ESTIMATION OF SWBM USING MANUAL CALCULATIONS

We have already shown some of the various presentations of the manual methods used for determining SWBM. To reinforce a previous point it again must be remembered that most manual methods give SWBM at one point, that being amidships.

The manual calculation procedures used for loading ships are based on the summation of moments from cargo, ballast, fuel and consumables. The calculated bending moments for some types of ships in their loading manuals are compared to a maximum allowable SWBM. Other loading manuals continue with the estimates of bending moment based on the "influence lines" approach. Accuracy of the results is good so long as the influence of trim on the buoyancy distribution is accounted for in the graphical data furnished in graphical form.

We feel the use of manual forms filled out by the ship's crew to gather SWBM loads data will not be satisfactory because:

1. While calculations of SWBM will be obtained, with the manual methods, no thermal or "other" effects of non-dynamic bending moment variations will be apparent. We feel it is possible that thermal

effects and "other" effects combined would be the same order of magnitude as SWBM variations due to load changes. To not measure the "other" effects would contribute to the uncertainties involved in statistical analysis of SWBM data.

2. Manual systems are not consistent from ship to ship, nor is the application or interpretation by individual crews. Inaccuracies, and in some cases data bias, would be prevelant.

3. The human element in reading tank levels, drafts, etc. is inherent in all methods; however, in the manual method there is no means of checking these errors as there is in the instrumented and loading computer alternatives.

4. Transposition of data in manual system from log to log and data reduction are not as efficient as instrumented and digital data acquisition and reduction methods.

5. There is no accurate manual method of assessing continuous changes in SWBM during the voyage.

The cost estimate in 1982 dollars for obtaining SWBM from manual means is summarized below.

1.	Formulate the format of the program, prepare forms	$ 15,000
2.	Contact ship operating companies, instruct crews, standardize loading manuals and distribute forms	$ 25,000
3.	Receive forms from 5 ships for 5 years, tabulate data and reduce to digital form	$100,000
4.	Analyze digitized data	$ 30,000
	TOTAL	$170,000

4.2. ESTIMATION OF SWBM USING LOADING COMPUTERS

Many of today's vessels are equipped with loading computers of either the analog or digital type. During initial interviews for this study, Bureau Veritas indicated that loading computers will soon be required on all newly built tankers of a certain size and that eventually loading computers will be required to be fitted to all tankers regardless of age. We expect this trend to continue as the economic and environmental consequences of improperly loaded vessels become intolerable. Regulatory bodies were interviewed and supported the use of loading computers and all indicated that mandatory requirements for loading computers are being considered.

As the cost and complexity of the shipboard loading computers decreases and crew sizes get smaller, the usefulness of such equipment can only be enhanced.

Several manufacturers of loading computers contacted gave an indication of current acceptance of these computers even without regulation requiring their use. Additionally, many software loading programs have been provided to shipping companies whose vessels have on board computers for other purposes such as payroll.

One of the prime advantages of a loading computer is that an infinite number of conditions can be investigated with relative ease before loading the vessel, therefore providing the officer with a truly optimal condition. The ease of use of the loading computer as opposed to the manual system actually encourages ships' officers to enter corrected data to obtain the "actual" condition, much the same as the manager who has to ask his secretary to make changes to text with a manual typewriter as opposed to a word processor.

In reviewing the operating practices of various ships, it has been our experience that manual pre-stow calculations may take place, but in most cases the actual loading will vary from the pre-stow. Often with the press of ship's business the final check on stowage, draft and stress is not made until the ship has departed. In order to attain proper trim for restricted channel depths, remedial ballast may have to be placed such that the projected SWBM is materially changed. Depending on the crew's perception of the difference in SWBM in a manual system, the recorded final departure value may be the pre-stow estimate. On the other hand, the relative ease with which a loading computer can be changed makes it reasonable to assume that the departure condition will actually be computed. A typical loading computer is shown in Figure 4-1. Each type of instrument has input dials and BM indicators on a backdrop of the given ship type.

We feel these units are well suited to shipboard application as they are visual in display, usually against a background "mimic" arrangement of the ship and they can be easily used by personnel with little training. A good feature of some loading computers is the deadweight meter and draft meter check. Any misdialed entry or misread data should be picked up when the manually totaled deadweight or draft and meter reading do not match.

The major disadvantage of the loading computers is that the conditions evaluated can only be preserved by copying input data and output data from the unit on to some sort of form once the condition is satisfactory. The usefulness of this type of computer would be enhanced if it were able to print out the data on command. Alternatively, a picture of the satisfactory computer condition could be taken to preserve the condition.

A less expensive alternative to the loading computer is a small desk top computer tied to a cathode ray tube (CRT) upon which various loading conditions can be analyzed. This type of computer requires some training for proper entry of data and interpretation of results. In addition, the data display is tabular and thus may not be as meaningful to the ship's officer as the "mimic" display.

Regardless of the actual hardware used it is the opinion of the authors that consistency and accuracy will be significantly enhanced if loading computers are used.

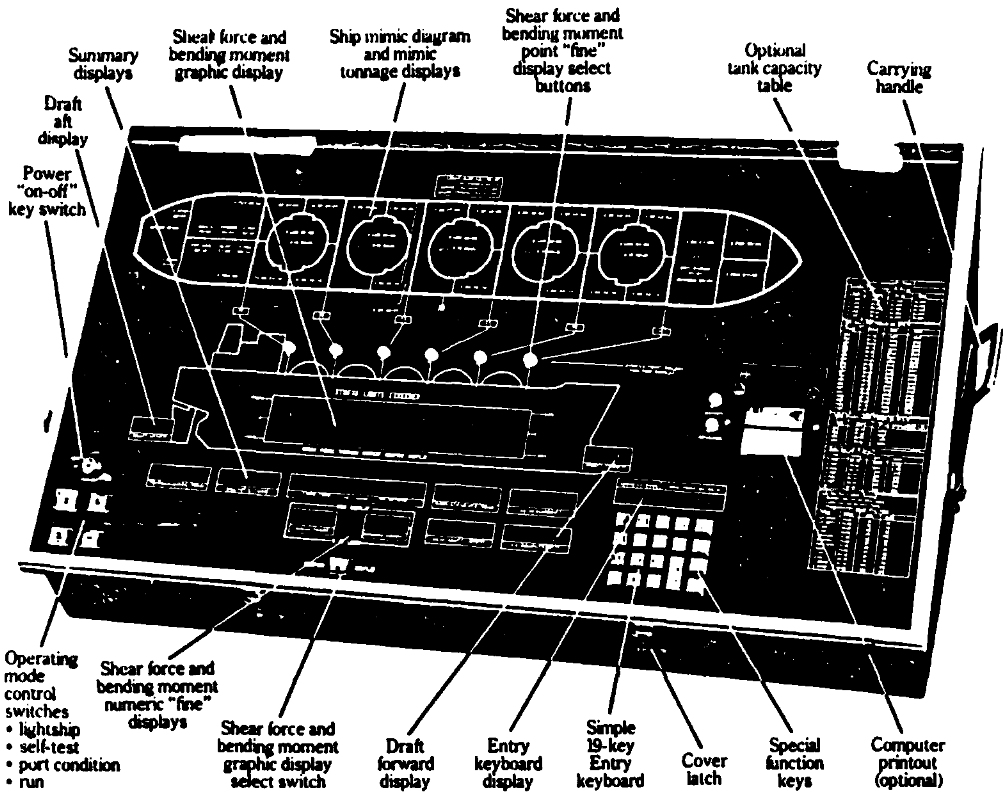


Figure 4-1 Typical Shipboard Computer

The estimated cost in 1982 dollars of obtaining SWBM information from loading computers existing on selected ships would be:

1.	Organization of program, develop forms and instructions	\$ 10,000
2.	Contact 5 companies and instruct crews, distribute forms*	\$ 15,000
3.	Receive forms from 5 ships for 5 years, reduce data to tabular form and digitize	\$100,000
4.	Analyze digitized data	\$ 30,000
	TOTAL	\$155,000

* If SWBM calculator has to be purchased, the desk top unit costs about \$15,000 and the loading computer about \$25,000.

4.3 ESTIMATION OF SWBM USING INSTRUMENTATION

Instrumentation is designed to record all changes in strain after the gauges are installed. The record of strain prior to the installation of gauges due to built in, residual or light ship stresses is not known. A determination must be made of the bending stress induced by the light ship and cargo distribution existing in the structure at the time the gauges are energized. After the gauges are attached the instrumentation will respond to all changes in stress regardless of whether or not the data acquisition equipment is recording.

The instrumentation records all stresses induced from sources of loading, typically:

a) Cargo loading
b) Ballast shifts
c) Fuel and water consumption
d) Ship wave train
e) Thermal effects
f) Wave-induced at wave encounter frequency
g) Wave-induced high frequency loading occuring near the hull's first natural mode of vibration.

These loading sources produce a combined stress time history depicted in Figure 3-5. With all loads combined as would be in a measured and recorded strain, some scheme must be employed to separate the SWBM-induced strain from all other strain components. To this end, strain and temperature information should be obtained to determine SWBM from measured data.

4.3.1 Strain Measurements and Types of Instrumentation with Suitable Alternatives

Traditionally strain gauges have been used to obtain strain information from the response of ship hull structures. However, strain gauges have

limitations in obtaining accurate SWBM data both in port and at sea throughout the instrumented period. These primary limitations of strain gauges used to acquire SWBM information include gauge drift over long durations, and separation of the SWBM from dynamic strains such as those induced by the encounter of waves. An integrated data acquisition system would have to be designed to minimize these limitations.

Several other types of instrumentation were examined for applicability of obtaining SWBM information. These include vibrating, "singing," wire technnology. Each type of instrument responds to the strain occurring in the ship's structure but each has limitations of its own.

There are several trade-off considerations involved in selection of a gauge to obtain SWBM data. The strain gauges have drift characteristics that are of the order of magnitude, and in some instances, the frequency, of the changes in SWBM. Vibrating wire strain gauges exhibit very stable zero characteristics; however, they reach their maximum sample frequencies at the frequencies of whipping and springing-type occurrences.

Electronic strain gauges are notorious for their instability and tendencies to drift back toward the original gauge zero at various rates. In many instances the strain gauge drift may be on the order of magnitude of SWBM induced strains. Techniques have been developed (9) to compensate for the gauge drift. These include modifying the gauges themselves and developing correction techniques that would be employed during data analysis. The types of modifications to the electronic strain gauges include proper adhesive selection, post temperature curing and cycling the gauge prior to installation. The electronic strain gauge drift may also be compensated for by reversing polarity of the electrical input and developing relationships between drift and frequency of drift to be applied to the measured strain.

These techniques for electronic strain gauge drift compensation are approximate at best and may yield unreliable data when the dynamic environment encountered by ships in service is considered.

Vibrating wire technology has been developed and applied to measurement of quasi-static variations in strain. The vibrating wire drift is negligible relative to the magnitude of strain being measured. The vibrating wire consists basically of a wire that is "plucked" and vibrates at very high frequencies (approximately 1000 times/sample). The variations in vibration frequencies may be calibrated to determine levels of strain experienced by the tensioned wire.

The vibrating wire gauge produces a digital sample. The vibrating wire strain gauges have a sampling frequency ranging from 10 Hz to .1 Hz. The high-frequency end is just barely high enough to obtain information at the highest frequency to which the gauges are responding (i.e., whipping and springing). With either the strain gauge or vibrating wire gauge the higher frequency wave-induced loads would be separated from the SWBM as would other low-frequency effects by arithmetic averaging of the wave-induced cycles. The remainder of strains would be those induced by SWBM, thermal effects, ship's wave train effects and non-linearities discussed previously.

The averaging techniques employed to separate the wave-induced loads from other effects must balance the errors associated with the slower sampling frequencies. These averaging and sampling techniques are presented by Bendat (10,11) and must be employed for the particular gauges selected.

In summary, the vibrating wire technology produces a more stable zero drift condition than the electronic strain gauges. Instrumentation manufacturers have indicated that the vibration wire gauges are approximately ten times more reliable than the best electronic strain gauge. The vibrating wire strain gauges are thus recommended for obtaining measured SWBM data.

4.3.2 Temperature Measurements and Compensations

Although the strain gauges are compensated for thermal-induced gauge effects, they still respond to thermal-induced strains on the deck plating. Therefore, some means must be applied that would allow the separation of the thermal-induced stress from SWBM-induced stress. The temperature of the air and water will be recorded as part of the logbook data. The temperature measurements should be obtained at the locations where stress is inferred from strain measurements and at the same sampling frequency as the other measurements. The temperature information would be merged with the information on the final magnetic tape for data analysis. The anticipated temperature ranges of the steel deck would be between 30°F to 150°F, depending on deck color and amounts of shading. Some extremes could be expected outside of this range.

The analysis of temperature data as noted above can only be used, in our opinion, to infer some sort of thermal stress. To be completely rigorous, it would be necessary to instrument the ship universally with perhaps 200 thermal gauges and to then analyze the entire hull girder with a detailed structural model such as a finite-element analysis.

4.3.3 Data Reduction and Analysis Required to Infer SWBM from Measured Strain Data

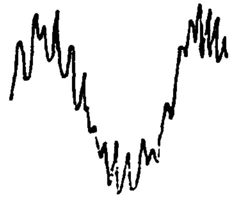
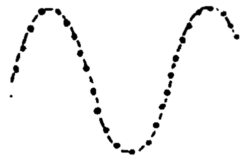
In order to show the difficulty of providing an instrumentation package that would provide SWBM information, the following tabular format has been prepared and presented in Table 4-1.

The data analysis and reduction procedures indicated in Table 4-1 illustrate the effort required to properly segregate SWBM from other effects and to provide a validation comparison of that data, a great deal of engineering will have to be accomplished before and during such an instrumentation program. After SWBM is inferred from measured strain by rigorous methods, there is no guarantee or verification that the end result is in fact SWBM.

From a technical standpoint, it is important to note the estimated range of stress variance in each step and to balance these variances against known variances (gauge drift, thermal effects, etc.) in instrumentation.

TABLE 4-1

Example of the Data Reduction and Analysis
Required to Compare SWBM Inferred from
Measured Data to Calculated SWBM

Type of Data Reduction & Analysis	Results	Character of Data (Stress vs Time)	Order of Magnitude of Resultant Excursions
1. Strain Data	Measured low-frequency: SWBM thermal ship's wave train wave-induced transient		Measured low frequency, wave-induced and 25,000 psi transient
2. Strain data with high frequency effects averaged out	Inferred low-frequency: SWBM thermal ship's wave train		Inferred low frequency, inferred SWBM/thermal/ship's wave train, 8,000 psi
3. Data from 2 with estimate of BM from ships wave train, analytically, from similar ships or model tests	Inferred low-frequency: SWBM thermal		Inferred SWBM/thermal 7,500 psi
4. Data from 3 coupled with finite-element calculations of thermal effects based on thermal instrumentation gauge array	Inferred low-frequency: SWBM		Inferred SWBM 3,000 psi

It is for this reason we feel it would be more practical to design a system that would measure SWBM, thermal and ship wave train strains (low-frequency strains from Table 4-1, Item 2) and compare them to calculated SWBM data from a shipboard loading computer. In this manner the "differences" in calculated and measured data should account for:

1. Gross thermal effects
2. Ship wave train effects
3. Any other low-frequency effects.

This option is pursued in greater detail as the recommended system to obtain SWBM data and is presented in Section 5.0.

4.3.4 Cost Estimate for Inferring SWBM from Measured Data

The cost for conducting an instrumentation program to obtain data to infer SWBM has been estimated in terms of 1982 dollars to be:

1.	Organize and develop the program	$ 35,000
2.	Purchase hardware ($60,000 per ship)	$300,000*
3.	Installation and operation of system (including data reduction for 5 ships for 5 years)	$170,000
4.	Analyze digitized measured strain data	$ 80,000
	TOTAL	$585,000

* The total cost of the instrumentation program could be reduced substantially if the hardware is available to the instrumentation group.

4.4 SUMMARY OF VARIOUS ALTERNATIVES TO OBTAIN SWBM

The various alternatives and costs for obtaining SWBM data have been described in the previous sections along with discussion of advantages and disadvantages. An estimated cost of each alternative has been included to further illustrate the differences between the various methods to obtain SWBM.

The high cost of the manual method for obtaining SWBM reflects the added documentation required to minimize the inaccuracies inherent in the data acquisition. In our opinion, although additional money and effort can minimize the inaccuracies, they do not totally alleviate the disadvantages of the method.

A better method is to perform the same collection and analysis of shipboard loading computer data for reasons of consistency and accuracy.

It should be remembered that the manual and calculation systems rely on the ship or shipping company sending out forms after the initial training session and the ship and shipping company returning these forms. There are no costs included in the estimates of 4.1 and 4.2 for any visits to any ships other than the initial training trip with one crew.

Similarly, the instrumentation system is assumed to be unmanned and employs a trained ships officer(s) to operate the equipment. No costs have been included in the estimate under 4.3 for visits to the ship(s) other than the initial set up and indoctrination trip.

Each of the alternatives presented has such limitations that we do not propose any one system but a combination of instrumentation (4.3) and loading computer (4.2) as will be described in the next section.

5.0 RECOMMENDED SYSTEM TO OBTAIN SWBM DATA (REQUIREMENTS AND SPECIFICATIONS)

Of the alternatives discussed in Section 4.0, none individually fulfill the objectives and requirements of obtaining SWBM data for statistical characterization of lifetime variations. The recommended system that would best fulfill the objectives and requirements for the SWBM plan would be a combination of alternatives discussed in Sections 4.2 and 4.3. A combination or variation of the SWBM calculation equipment and a greatly reduced instrumentation program are recommended to obtain the appropriate data to characterize SWBM. Calculation equipment would provide the best information for determination of statistical variations in SWBM and an instrumentation system that provides supporting data would allow comparisons between calculated data and measured data.

5.1 DEFINITION OF THE DATA ACQUISITION SYSTEM

A schematic of the proposed system to obtain SWBM data is depicted in Figure 5-1. The schematic presents the relationship of the data processing system.

A summary of the recommended instrumentation system components to be installed on the selected ships is presented in Table 5-1 along with the purpose of the instrumentation as it relates to the ship of interest. The data acquisition system consists basically of SWBM calculation equipment, CRT, data recording and reduction equipment and vibrating wire strain gauges. This summary includes a description of the instrumentation, its purpose and its interaction with the ship.

The SWBM information would be inferred from the "strain data" measured at various locations along the length of the ship to provide information that will enable those involved in data analysis to determine the longitudinal distribution of SWBM and the approximate location of maximum SWBM relative to the ship's longitudinal axis. These locations will generally be in the midships 0.4 L of the main hull girder and forward of the engine room for ships which have the engine room located aft. Variations in the location of the gauges will depend on ship type; however, an example of the gauging locations for a bulk carrier is depicted in Figure 5-2. Note that to provide direct comparison the strain gauges in Figure 5-2 are located at the same points that are calculated on the loading computer.

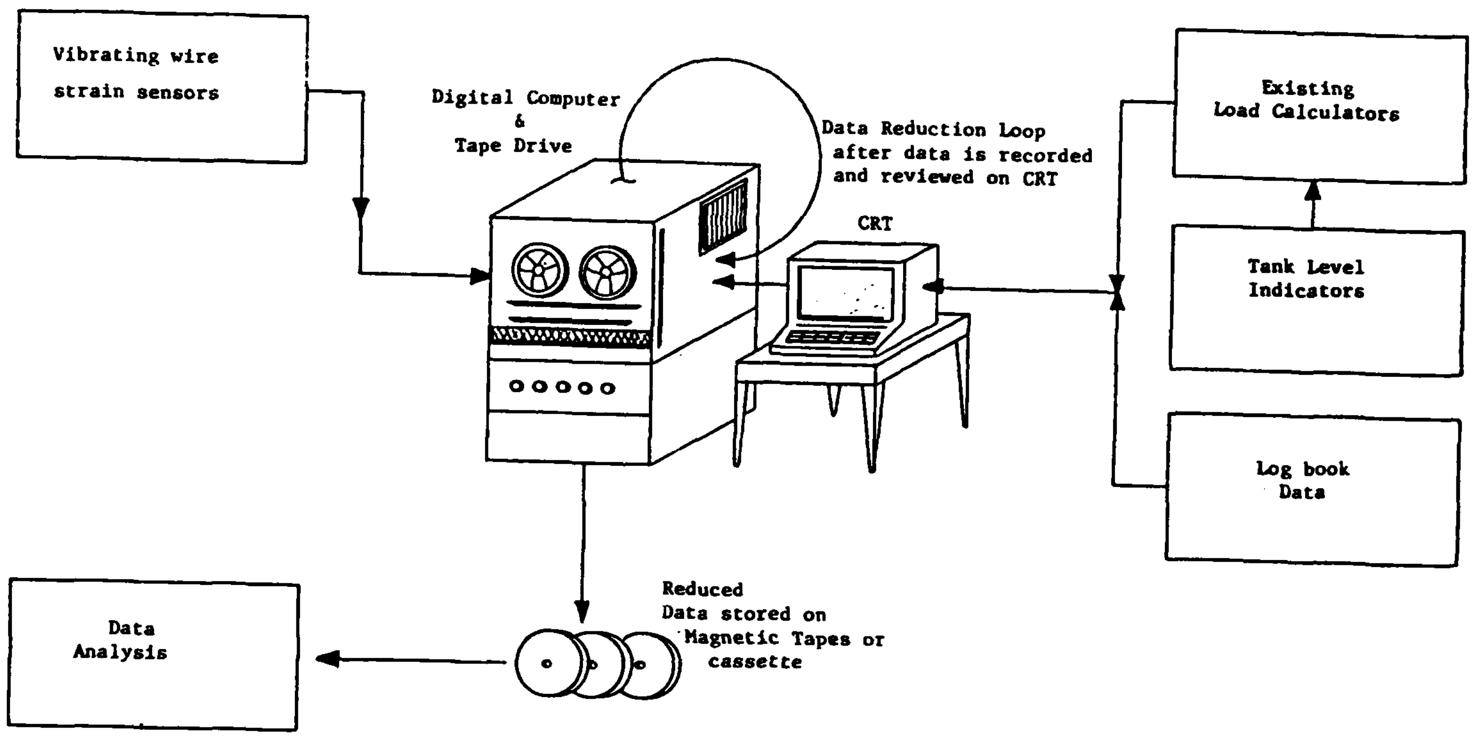


Figure 5-1 Data Acquisition Scheme to Obtain SWBM Data, Both In Port and At Sea

TABLE 5-1

Summary of Proposed Instrumentation System to Obtain SWBM Information

Instrumentation	Purpose	Ship Instrumentation and Interaction
1. SWBM Calculation Equipment	The calculation equipment should be included in the instrumentation system to calculate SWBM information from cargo distributions, ballast variations and consumable variations at various locations along the length of the ship	Located conveniently to be accessible by operational personnel from the instrumentation group and near the tank capacity indicators (ballast fuel and cargo tank capacities are input to the calculation equipment).
2. CRT tied to the recording equipment	The CRT will be used to input the SWBM information calculated at various locations along the length of the ship and logbook data.	The CRT should be on board located next to the SWBM calculation equipment but connected to the data recording equipment for data acquisition and reduction.
3. Signal conditioning and recording equipment	The signal conditioning equipment will be used to process the data (filter, amplify as required) and to record the measured stress and thermal information. The recording equipment should be digital and would accept input from the CRT described above. The recording equipment should also be capable of reducing the measured and calculated data and output the reduced data on magnetic tape.	Located conveniently to be accessible by operational personnel from the instrumentation group. The conditioning and recording equipment should be assembled to the cabling from the instrumentation.
4. Vibrating Wire Strain Gauges	The strain gauges will be used to measure SWBM-induced strain by using vibrating wire gauges with very stable zero characteristics. The gauges would be located both port and starboard along the length of the ship's deck to infer longitudinal vertical SWBM from the measured strain.	Attachment of strain gauges to the deck structure and protective cover bolted on to studs welded to the deck structure. The cabling extends from the instrumentation to recording equipment (see Figure 5-2).

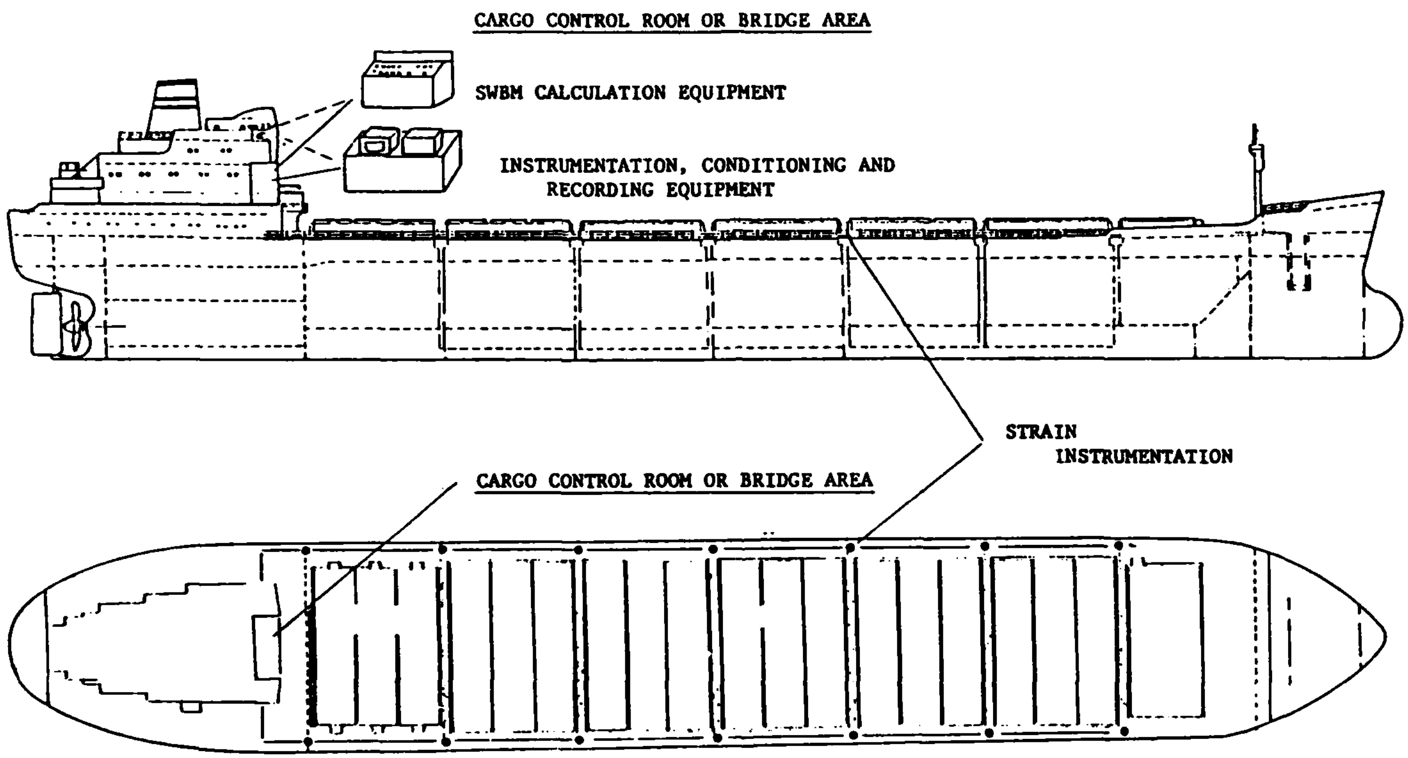


Figure 5-2. Typical Schematic for Instrumentation Layout

5.1.1 Equipment Required to Calculate SWBM Data

In many ships, loading calculators are already used to control SWBM as discussed in Section 4.2. If such calculation equipment is available for use, the output SWBM obtained for each sample may be entered through the CRT and combined with the measured data on the final magnetic tape used for data analyses.

The calculation equipment (loading calculator or equivalent computer) would be used to calculate the SWBM from the weight and buoyancy distribution of the cargo, ballast, consumables, lightship and ship hull respectively, and then entered in the recording equipment through a CRT. The system should also include the hardware and software to record and reduce the measured strain and temperature data.

The SWBM calculation equipment is to be configured to obtain SWBM information at locations on the ship. There are numerous hardware and systems currently available commercially that are able to calculate SWBM. They include desk top computers, both analog and digital versions. Since digital equipment will be available for the instrumentation system it could be modified to perform the calculation of SWBM to augment the measured data. Commercial software is available that could be used with this equipment to determine SWBM.

The SWBM calculation instrumentation should be located near ship loading and capacity instrumentation so that the instrumentation operator will be able to monitor all changes in the ship loading such as shifts in ballast, cargo (tankers) and fuel at sea, and during the loading of the ship in port. The loading information must be obtained and input into the SWBM calculation equipment faithfully since related errors would be cumulative.

The calculated SWBM would be recorded by the main computer via a CRT and keyboard.

The output calculations of SWBM from the loading and ship information would be obtained for the same or a multiple of the intervals that SWBM-induced stress is sampled, reduced and recorded. If no changes occur to SWBM during the sampling period, the calculated SWBM would be stored as a constant until a change to the calculated SWBM was made and input via the CRT and keyboard. As discussed in the data reduction Section 5.2, a final tape should be produced that would contain header information, logbook information, measured SWBM and calculated SWBM.

The calculated SWBM data should be accompanied by identification information merged with the required logbook information so that each tape presents a complete history. The input loading distribution information should also be summarized and stored on the magnetic tape for future data analysis and collation.

As discussed in Sections 2.0 and 3.0, the statistical characteristics of the SWBM data in many instances, are influenced by the methods used to control SWBM. The limits placed on SWBM by regulatory bodies tend to truncate

statistical distributions as restrictions are warranted for various types of ships (tanker, container, LNG, etc). Generally ships equipped with loading manuals or SWBM calculators indicate that the given ship may have a SWBM restriction. The ships selected for this study may have SWBM calculators on board that affect SWBM ranges. Consideration should also be given to placement of the calculation equipment and instrumentation on ships that have no predetermined restrictions so that the calculation equipment does not produce an artificial statistical bias to SWBM data which would otherwise be unrestricted.

5.1.2 Instrumentation for Data Processing and Recording

The SWBM data acquisition system will serve a dual purpose, namely recording calculated SWBM information and recording the measured data. The data acquisition system would include signal conditioning and data recording equipment. The data recording equipment would also contain the software capable of accepting calculated SWBM and logbook data.

The data acquisition system measures the digital parameters from the vibrating wire strain gauges and includes amplifiers where necessary.

Various types of equipment and methods for recording data are presently available commercially.

The historic scheme is to use an FM tape recorder to periodically calibrate and record an interval of data (typically 20 minutes long) preceded by calibrations and analyze the tape after it has been removed from the ship. This system is generally used to obtain large amounts of data (10 to 100 channels). While this scheme records the complete analog record, it is somewhat cumbersome in space and labor required.

If the desired parameter (e.g., mean strain, root mean square (RMS) level, number of peaks, histogram) can be defined in advance, equipment exists for reducing the data. Such equipment need only be interrogated occasionally to remove the data from memory. These devices are compact and are generally limited in number of channels of data, typically 1-3.

The most common type of data recording system employed for data acquisition is the digital computer. Analog signals from sensors are converted to digital signals and recorded as on the computer in time series format. Generally the number of channels of recorded digital data ranges from 5 to 15 per recorder.

Digital computers are recommended for recording the calculated and measured data. A computer with a mass storage subsystem, disk drive and read/write electronic module can be obtained commercially. These units should be adaptable for shipboard applications provided they are mounted in an air conditioned environment.

5.1.3 Instrumentation to Obtain Measured Strain Data

Because of the difficulties associated with determining SWBM from measured strain, a reduced instrumentation system is recommended that would facilitate comparisons between calculated SWBM and the quasi-static (induced from thermal effects, SWBM, etc.) BM inferred from measured strain. The purpose of measuring the quasi-static BM-induced strain is to be able to relate the measured data to calculated data, infer the relative difference between them and not to obtain absolute SWBM from the measured data. As discussed in Section 4.3, it becomes extremely difficult to separate SWBM-induced strain from other strains with any level of confidence.

5.1.3.1 Description of the Instrumentation

To this end we recommend an instrumentation system which includes vibrating wire strain gauges along the length of the ship to obtain longitudinal vertical bending-induced strains as described in Section 4.3. Bending moment data may then be inferred from the strain data during the data reduction and analysis phases.

The instrumentation output will be processed, recorded and reduced by the digital computer that is used to record the calculated SWBM (for locations along the ship's length). This system is shown in Figure 5-1. The measured data should be merged with the logbook information and calculated SWBM. The basic considerations for the instrumentation discussed in Section 4.3 apply here only if the system does not include temperature information measured along the length of the ship.

The number of data channels for the digital vibrating wire strain gauges would equal the number of gauges used. The example of gauge locations presented for the bulk carrier shown in Figure 5-1 has seven port and starboard pairs of gauges. The total number of data channels for this example would be 14. Longitudinal vertical bending may be obtained from each of the port and starboard pair of gauges by averaging the data channels from each after the data is acquired. Considerations for the selection of strain gauge and their operation are discussed in Section 4.3 and apply to the system recommended here.

5.1.3.2 Instrumentation Installation

The equipment required to obtain SWBM data should be installed by the instrumentation group with the cooperation of the ship operators on a schedule that would not interfere significantly with the ship's operation. The installation of recording equipment may be accomplished at almost any time prior to the data acquisition. However, the strain gauges should be installed on the ship for a condition where the loading condition of the ship is known. This includes the estimation of light ship weight and all dead weight aboard, along with an estimation of the weight location. This could be accomplished for a new ship before trials. After ships are in service, the gauge installation may be scheduled around a drydocking or, if not otherwise practical, for a departure condition where loading conditions are known. The purpose of installing the gauges when the loading condition of

the ship is known is to be able to estimate the magnitude of SWBM or base condition as seen by the stress/strain gauges. All SWBM stress measurements would be referenced to this initial condition. The objective is to measure longitudinal vertical bending stress induced by changes in SWBM. Generally, the instrumentation should be placed to assure measurement of the gross representative bending stress. In each case, the substructures should be studied to make certain that the transducers are not located near complex configurations such as cutouts in the longitudinal girders. The presence of lateral girders or bulkheads in the vicinity of the transducers does influence the lateral strains locally but does not have any measurable effect on the accuracy of the longitudinal stress or strain measurements.

5.1.3.3 Instrumentation System Calibration

It is usual to calibrate an overall instrumentation installation in order to perform an overall system check and calibrate instrumentation variances. To provide a comparison between measured and calculated bending stresses at deck gauge locations, the hull is cycled from a large hogging stress to a large sagging stress and back to zero.

Two major problems are associated with this event: keeping the ship in a constant environment (i.e., a cloudy, even temperature night) and getting enough load changes (i.e., by ballast or cargo placement). Major sources of error arise from insufficient loading or masking by environmental changes.

Although the proposed procedure to obtain SWBM includes measurement and calculation of stress, the base calibration should be performed under conditions which will minimize thermal stresses. The ideal situation is an overcast, windless night occurring after a similar day. The calibration should be performed in the shortest time possible; however, for the SWBM study this calibration experiment should not be conducted hastily. Partial funding should be considered to reimburse the ship owner for having the ship out of service and hopefully minimize the temptation to rush through the calibration experiment.

The SWBM calculation equipment installed on the ship will facilitate the calibration. Calculations of the loading conditions and resulting SWBM may be obtained and plotted as the experiment is conducted.

The information obtained during the calibration experiment should include:

1. Condition of all cargo, ballast and fuel tanks
2. Drafts forward, amidship (both sides) and aft
3. Average stress at each location
4. Deck temperature at each location
5. Air and water temperature, wind velocity and direction, weather conditions

If time and funds permit, consideration should also be given to conducting a calibration of stress gauges to aid in separation of thermal effects. Data should be obtained during several days of calm water sailing with various percentages of cloud cover and sun to get as many conditions of cloud cover and sun as possible.

5.1.4 Pertinent Measurements to Support SWBM Information for Collation Purposes

The designated watch officer will enter the logbook information into the instrumentation recording system daily. The logbook data should be combined with the other measured and calculated data as indicated in Figure 5-1. It should be input by means of the CRT and appear on the final magnetic tape. The logbook information is necessary for analysis of factors which influence SWBM data. The typical information available as logbook data is indicated in Table 5-2.

5.1.5 Data Acquisition System Operation

The instrumentation installed on the ships to obtain SWBM information should be operated and maintained by an instrumentation group. This instrumentation should involve only the SWBM measurement instrumentation. The SWBM calculation instrumentation may have to be operated and maintained by the ship's crew if it is existing, or even if put on board for the purpose of this study the owner still may wish it maintained by someone other than the instrumentation group.

The duration and frequency of the instrumentation system operation are discussed in the following sections along with the manning requirements. For optimum performance the systems should be manned by qualified trained personnel to ensure data acquisition is working properly and to properly enter data from the SWBM computer. It is also desirable to have trained personnel to record the logbook information as data logging and header information and to annotate the data.

There are two alternatives in manning:

1. Place a representative of the instrumentation company on board who is familiar with the operation of all sensors and conditioning and recording equipment. It should be remembered that unlike wave bending moment programs, SWBM occurs all year long and thus a manned effort will involve a full year of ship riding per year.

2. Train a radio operator and/or deck officer in the operation of all conditioning and recording equipment without making him responsible for sensor maintenance or repair. This trained member of the crew should be capable of troubleshooting and repairing conditioning and recording equipment. Because present crew working rules require they work one-half of the year, two personnel for each position will have to be trained.

Of the two alternatives we prefer number 2 for the following reasons:

a. It has been difficult to obtain instrumentation personnel to ride ships for long periods of time and the frequent travel for rotations adds to the overall cost.

TABLE 5-2

List of Typical Logbook Information

Ship
Voyage
From
To
Date of Departure
Date of Arrival
Date of Log Entry (M, D, Y)
Time (GMT)
Noon Position a) Latitude
b) Longitude
Course
Average Ship Speed
Average Engine RPM
Relative Wind Speed
Relative Wind Direction
Beaufort Sea State Number
Barometer Reading
Sea Temperature
Air Temperature
Weather
Comments

b. Ship crews have improved technically in recent years with the addition of machinery automation and computer-aided radar plotters.

c. The SWBM program is not as demanding in terms of data recorded as previous programs, thus it may be tedious to a shoreside instrumentation specialist while at the same time small enough to be worked into the crew's normal schedule.

d. There would be a definite asset in having crew participate and company support such a program.

e. On a total cost basis, if the ship owner would support some of the crew overtime, the cost should be less. It would be easier and more practical for a ship owner to support his own crew overtime than the cost of an outside third party.

5.1.5.1 Data Sampling Procedures

The SWBM stress, temperature and calculated data should be obtained on a simultaneous sampling pattern for both in port and at sea.

Statistical considerations dictate that data should be obtained about every four hours at sea. This will vary for the different ship types considered as part of this study.

A minimum of one sample every four hours is required to define thermal effects which occur in a 24-hour cycle. Some container ships (SL-7 SEA-LAND McLEAN, for example) consume large amounts of fuel and thus change ballast every watch and an increased sampling pattern is required to define the changes in SWBM, say once every two hours. Tankers on the other hand, do not exhibit frequent changes in SWBM (as indicated in Figure 3-5) and thermal effects are the dominant frequency. For tankers it might be possible to sample once per day at midnight or whenever any ballast or cargo changes are made.

The in-port sampling period would also vary from ship type to ship type. As discussed in Section 3.0, bulk carriers exhibit more frequent fluctuations than tankers during loading and unloading cargo. Again, one sample every two hours would be adequate to define the SWBM during loading of cargo with variations warranted as special cases arise. In line with recommendations in manning, if the loading/unloading operation conflicts with ship's crew data taking, the instrumentation representation could take data during loading/unloading.

Typical data acquisition cycles and sampling patterns are presented in Table 5-3.

The actual data sample should be at least a half an hour for most types of ships if filtering and averaging techniques are used to separate SWBM and wave-induced stresses.

TABLE 5-3

SWBM Data Acquisition Cycle Measurements and Calculations

	Typical Duration of Ship Loading	Sampling Pattern In-Port Loading	Sampling Pattern At Sea	Sampling Pattern In-port Unloading	Typical Duration of Ship Unloading
Tanker	12-24 hr	2 hr	4 hr	2 hr	24 hr
Bulk Carrier	24 hrs Lakes < 8 hr	2 hr	4 hr	2 hr	24 hr
Containership	8-12 hr	2 hr	2 hr	2 hr	8-12 hr
General Cargo	24 hr	4 hr	4 hr	4 hr	24 hr

5.1.5.2 Extent and Duration of Tests Required to Obtain SWBM Data Which is Statistically Representative

The methods for determining the general duration of tests include comparing with previous samples, conducting pilot studies and/or using sample size estimators. The sample size estimates for predicting the extent of data required to be statistically meaningful are presented in references 12, 13 and 14. These methods include factors related to tolerance and confidence limits of data and are based on the variance estimated from a previous data sample. Although the methods are approximations they indicate the sample size that would provide a level of confidence in extrapolated data.

Estimates of sample size for SWBM data were obtained using limited amounts of SWBM-induced stress data presented in references 2 and 3 for the SL-7 SEA-LAND McLEAN, UNIVERSE IRELAND and FOTINI L. Based on these samples of data (voyages and seasons), the sample size estimators indicated that as many as five years (20 voyages/season/ 2 seasons/year sampling once every four hours) would be required to produce an adequate statistical sample assuming that the SWBM data will be within 10% of the correct figure with a 95% assurance. These five years should include both winter and summer operations since loading and ballasting procedures may vary for each.

The statistical estimators tend to be conservative in estimating the appropriate sample sizes required to produce meaningful data. The best way to insure that the data is statistically sound is to reduce the SWBM data as it is obtained, and analyze the reduced data, preferably after each voyage but most definitely after each season. The preliminary data analysis between voyages need not be as extensive as analyzing all the data before the ship begins a new season; however, statistical tests and distribution fitting conducted on the data after it is recorded and reduced insures that adequate data is obtained and an evaluation of the data sample (based on statistical tolerance and confidence limits) may be assessed continuously. The extent and duration of the SWBM program may then be evaluated and determined as soon as an adequate amount of data has been obtained.

5.2 DATA REDUCTION FOR SWBM

The objective of the data reduction phase of the SWBM program is to produce an industry standard magnetic tape(s) that has header information, logbook data, reduced measured SWBM stress and calculated SWBM for the sampling patterns for both in port and at sea. This tape should be ready for data analysis as soon as it reaches the facility that will analyze the data.

Immediately after a complete sample of all data is recorded by the recording equipment, the data should be reduced and merged with the appropriate header information (sample identification) and logbook data. This would be conducted by looping the data back through the computer after it is acquired and having the appropriate software reduce the data for each recorded sample. The information for each reduced 20-minute data sample both in port and at sea should include:

1. Sample identification information

2. Logbook data

3. Measured SWBM-induced strain at the specified locations along the length of the selected ships

   a. Average SWBM
   b. Maximum SWBM
   c. Minimum SWBM

4. Calculated SWBM for all locations along the length of the ship

Discussions with outside researchers and the American Bureau of Shipping indicate that digitized data are most desirable because they are easier to work with. Some researchers, however, indicated that they would not feel comfortable with digitized data that had not been reviewed in its analog form by a qualified individual and some even indicated that for "unusual" data they would prefer to have a copy of the analog trace.

Our recommendation is to have voyage data reviewed in its analog form on board the vessel at the start of the instrumentation program by a representative of the instrumentation contractor. During this early review "unusual" data would be found and system corrected to ensure the system is working before large amounts of data are acquired later in the program. After the initial system check out, the data collected for each sampling interval should be reviewed in digital form channel by channel to look for spurious points in the data and other data inconsistancies before it is looped back through the system for data reduction.

5.3 DATA ANALYSIS AND PRESENTATION

The objective of this study is to characterize the SWBM data in a probabilistic sense. Those involved in examination of past data (1,2,3) suggest that the variations of SWBM at sea should be approached probabilistically and in some instances deterministically as related to a design procedure. The statistical approach to characterization of SWBM involves the development of long-term distributions that may be combined with bending moment from other sources to form a lifetime hull girder load criteria for given ship types. The authors of SSC 240 (1) have indicated that at-sea SWBM data may follow the normal statistical distribution. However, separate distributions were developed to full load and ballast conditions for ships (i.e. tankers) which have large differences between full load and ballast conditions since the wave response may be affected by loading conditions (slamming, etc.). The authors of SSC 287 (2) stated that their objectives were to examine SWBM data and determine if SWBM lends itself to complete or practical probabilistic description, or if it should be approached deterministically. SWBM-induced stress data was examined for the SL-7 SEA-LAND McLEAN, FOTINI L and UNIVERSE IRELAND. The authors concluded that there were indications that the SWBM tended toward normal distributions. They also observed that the SL-7 SEA-LAND McLEAN incurred low variations of

SWBM induced stresses during the voyages as a result of the extensive shore-side control and detailed instructions provided to the master. The extreme hogging condition induced by loading containers at the ends of the fine ships and loading restrictions on GM due to stability considerations necessitated these controls. The authors of SSC 287 recommended that a statistical estimate of the SWBM for design could be made from a truncated statistical distribution or even analyzed deterministically.

The data reduction would be oriented toward determining how the SWBM varies statistically or deterministically both in port and at sea. The measured and calculated data would first be compared to each other in an effort to account for differences statistically as shown in Table 5-4.

The comparison should be conducted between measured strain (including SWBM, thermal effects, ships wave train, and other effects) and calculated SWBM. In this manner the "differences" in calculated and measured data should be accounted for.

If statistical analysis of all data showed this difference to be statistically acceptable, it could then be inferred that the analytical calculation of SWBM combined with proper distribution of this difference could provide a reasonable estimate of the low frequency strains.

The SWBM data (measured and calculated) would then be analyzed to determine statistical distributions for various days, voyages, seasons, etc. and collated with operational information to note trends or factors which might bias the data (re: ship type, weather, operators, cargo type, etc.). Plots of SWBM would be generated similar to those shown in Sections 2 and 3 for both measured and calculated SWBM for each voyage in port and at sea.

It is suggested that the addition of loading computers and instrumentation will contribute to data bias if ship masters alter operational procedures such as more rigorous analysis of loading distributions while loading on cargo. The question of data bias will need to be addressed during data analysis if not quantitively by trends in data as the master and crew become familiar with the SWBM system, then subjectively by interviews with the ship's masters and crew. Instruction of instrumentation operation should be directed toward familarizing the master's crew so that they accept the system as part of normal functions in ship operations.

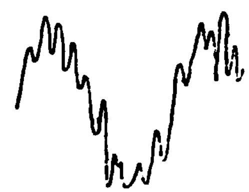
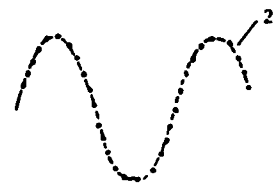
The SWBM data analysis should include the selection of the most appropriate distribution in given circumstances using normality tests, Chi-squared tests and confidence levels determined for statistical distributions for the various voyages (in port, at sea, inbound, outbound), seasons and total data sample.

5.4 COST FOR COMBINED CALCULATION & INSTRUMENTATION PLAN TO OBTAIN SWBM DATA

The cost in 1980 dollars for the recommended plan to obtain SWBM information from calculated and measured data has been estimated to be:

TABLE 5- 4

EXAMPLE OF THE DATA REDUCTION AND ANALYSIS REQUIRED TO COMPARE SWBM INFERRED FROM MEASURED DATA TO CALCULATED SWBM

Type of Data Reduction & Analysis	Results	Character of Data (Stress vs Time)	Order of Magnitude of Resultant Excursions
1. Strain Data	Measured low-frequency: SWBM thermal ship's wave train wave-induced transient		Measured low frequency, wave-induced and 25,000 psi
2. Strain data with high frequency effects averaged out	Inferred low-frequency: SWBM thermal ship's wave train		Inferred low frequency, 8,000 psi
3. SWBM inferred from measured data from 1 and 2 compared with calculated SWBM			Calculated SWBM 2,500 psi

1.	Organization of the program and development	$ 45,000
2.	Purchase hardware ($60,000 per ship)	$300,000*
3.	Installation and operation of the system (including data reduction for 5 ships for 5 years)	$150,000
4.	Analyze digitized measured strain and calculated data	$ 55,000
	TOTAL	$550,000

* Assumes loading computer is installed on the ship prior to program initiation. If a loading computer or calculator has to be purchased, the desk top unit costs about $15,000 and a loading computer about $25,000.

5.5 PLAN IMPLEMENTATION

The Ship Structure Committee (SSC), a naval architecture firm, an instrumentation group and the ship operator(s) would be the primary participants in the program. The Ship Structure Committee would be responsible for monitoring the project and providing technical guidance which would be provided by an advisory committee. The relative level of effort anticipated for each participant is presented in Table 5-5.

An RFP would be issued which references this report. We feel this report provides a common basis for starting the project. The RFP would solicit team responses, each team consisting of a naval architecture firm, an instrumentation firm and ship operators. No partial responses for the RFP should be allowed as SSC should not be required to integrate and manage various entities. A written commitment from the ship owner(s) should be required. The recommended list of ship types for instrumentation to obtain SWBM data is presented in Section 3.3.

The responses to the RFP should include the contractor's proposed approach for:

1) Designing and developing an instrumentation system that would be installed on the ship(s) with the objectives and requirements for obtaining SWBM data for statistical characterization.
2) Installing, calibrating and debugging the instrumentation system that would collect and reduce the SWBM data in a form appropriate for data analysis.
3) Obtaining the SWBM data on the instrumented ship(s) and analyzing the data to determine preliminary estimates of data quality and quantity that is required for adequate characterization.
4) Conducting the data analysis required to characterize the SWBM data. Data presentation should include plots similar to those presented in this report along with plots of long-term distributions of SWBM for the respective ship(s).
5) Documenting the instrumentation system design, installation, calibration, operation, and data analysis. (This may be required for each of the respective items listed above.)

TABLE 5-5

Recommended Relative Level of Effort For Various Groups
Involved in the SWBM Instrumentation Program

	Program Management	Data Acquisition	Data Reduction	Data Analysis
Ship Structure Committee	30%	-	-	10%
Naval Architecture Firm	50%	10%	20%	80%
Instrumentation Group	10%	10%	40%	10%
Ship Operators and Owners	10%	80%	40%	-

The RFP would provide for a CPFF contract for a three-year base period with optional renewal years up to a total of five years. The duration of the program would be evaluated continuously as data is obtained. The cost estimates would be provided for one, two or three vessels instrumented due to possible budget constraints.

6.0 CONCLUSIONS AND RECOMMENDATIONS

1. A compilation of manual loading records will probably not produce a complete nor statistically acceptable sample of SWBM data. Previous studies have reached the same conclusion. These records will also not show thermal and other effects which should be measured to obtain a complete understanding of low frequency strains.

2. Loading computer records will produce more consistent and accurate SWBM data than manual loading records.

3. The direct measurement of SWBM by instrumentation is difficult due to the similar order of magnitude strains resulting from other low frequency loads produced by thermal effects, ships wave train and other undefined quantities and differences.

4. The most reasonable approach to obtaining SWBM data appears to the authors to be to measure low frequency strains and to compare them to calculated SWBM data. If this comparison remains statistically acceptable then total low frequency strains could be inferred for other ships based on the calculation of SWBM.

5. The following list of candidate ships is recommended in decreasing priority:

   a. Tankers
   b. Bulk carriers
   c. Barge carriers
   d. Containerships
   e. LNG, LPG, chemical carriers

6. A five-year program is recommended for any one ship to obtain a sufficient statistical sample of data. As many as five ships should be considered and preferably at least three types of ships should be considered to obtain a ship type distribution.

7. We recommend that data reduction and analysis be conducted with as little delay as possible after acquisition and reduction to ensure adequate data is obtained before conclusion of the program and to aid in determination of the duration of the program.

8. The recommended SWBM calculations and instrumentation program is modest in scope compared to most instrumentation plans. Effort was made to simplify the program to the extent possible. We recommend that the program remain as basic as possible. The success of gathering valuable data depends on well thought out programs with achievable, defined goals.

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